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ORIGINAL ARTICLES.

Origin of the "Beef" in the Lias Shales of the Dorset Coast.

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SOME years ago (in 1924–5) the writer was studying the occurrence and origin of the concretions and cone-in-cone in the shales-with-" beef " near Lyme Regis and Charmouth along the Dorset coast. His studies were greatly facilitated by the kindness of Dr. W. D. Lang of the British Natural History Museum, who was able because of his thorough knowledge of the geology of the area to direct the writer to the most ideal localities for study. The writer wishes to thank Dr. Lang for this invaluable aid and also for furnishing him not only with maps but with numerous sketches and notes that proved of great assistance. Recently, while revising the material on concretions and cone-in-cone for the volume *A Treatise on Sedimentation,* the writer had occasion to reread his notes and Dr. Lang's paper " The Shales-with-' Beef ' ",[1] and became interested in the origin of the " beef " (fibrous calcite), which was briefly discussed by Richardson.[2] As both Richardson and Taber remark, the origin of fibrous veins is an interesting problem. Each of these men has made valuable contributions to the subject. This paper presents a concept of the origin of the " beef " veins, and accounts, also, for the origin of the associated paper-shales.

Description of the Formation.

Dr. Lang divides the shales-with-" beef " into two divisions. The upper division (about 30 feet thick) consists of brownish paper-shales with more abundant layers of " beef " than the lower division (about 40 feet thick) which consists of various types of marls, dominantly bluish in colour.

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[1] W. D. Lang, L. F. Spath, and W. A. Richardson, " Shales-with-' Beef '," a Sequence in the Lower Lias of the Dorset Coast " : *Quart. Jour. Geol. Soc.,* lxxix, 1923, 47–99.

[2] Ibid., 89–90.

The " beef " consists of layers (some persistent, others very impersistent) of fibrous calcite. The individual layers range from $\frac{1}{16}$ in. to 4 inches in thickness. The great majority of these layers show at least one parting and some show five or six. The parting consists of a thin (possibly $\frac{1}{4}$-inch thick) layer of marl or shale. As a rule the portion of the layer above the parting (known as the " top ") is thicker than the root (the portion below the parting). The fibres are parallel and, as individuals, may extend from the parting to the outer surface or may pinch out to be replaced by other fibres. Richardson's studies showed the fibres to be elongated in the direction of the *c* or vertical axis. The fibres are not terminated by crystal faces. The size of the individual fibres varies widely, ranging from a possible thickness of $\frac{1}{8}$ inch to thicknesses less than those of a hair. If not continuous throughout the thickness of the " beef " the fibres are usually slender spindles, though numerous other elongated forms occur.

The " beef " is some shade (usually dark) of grey due to included carbonaceous material from the marls and shales. Cone-in-cone is found everywhere in the " beef ", but is best developed in the layers that are over an inch in thickness. The fibrous layers are parallel to the bedding-planes of the enclosing marls and shales. Some persistent layers may be followed long distances, other layers pinch out in a few feet. In disturbed areas the layers of " beef " may cross the bedding-planes but such occurrences are few and local. These shales-with-" beef " contain many large concretions, some of which are within a layer of fibrous calcite, the top of the layer passing over the concretion and the root under it.

The character and composition of the associated marls and shales are of importance as they have a bearing upon the origin of the fibrous calcite. The lower division consists dominantly of some type of marl, the amount of $CaCO_3$ present varying in different beds. The texture and density of the marls also vary widely, some beds being very porous and friable and others so strongly indurated as to be almost limestone (in fact, a few beds of limestone, more or less tabular or lenticular, do occur). Calcareous concretions occur in different parts of this division. Fairly thick and persistent " beef " layers occur in the lower part of the lower division (in beds numbered 55 to 65 of Lang's section) and other layers are scattered throughout it but, on the whole, there is considerably less " beef " in this division than in the upper division.

The upper division consists dominantly of paper-shales. It contains some concretions and lenticular limestones but very little marl. More " beef " seams are present in it than in the lower division. The lenticular limestones and concretions in beds designated by Lang as 74 *p*, 74 *r*, and 75 *a* are surrounded by fibrous calcite.

AGE OF THE "BEEF".

The veins of fibrous calcite are undoubtedly later in origin than the enclosing rock. This is evidenced by the veins that *cross* the bedding-planes. The layers are, also, younger than the concretions, over and under which they have grown. In another paper (in Press) the writer is citing proof that the formation of the concretions in these shales was contemporaneous with the deposition of the enclosing beds—that is, that they were formed after the beds below them and before the beds above. These concretions show horizontal bedding-planes that are discontinuous with those of the beds above and below. These beds curve over and under the concretions. Such a relationship could have come about only by a primary deposition of the concretions. Therefore, if the concretions and lenticular limestones are the same age as the marls and shales, there can be little doubt that the "beef" is later. Richardson states that the "beef" is earlier than the folding which involved the Lias along this part of the south coast, since the "beef" conforms to the folding and has been faulted along with the other materials. The "beef" was formed, then, subsequently to the deposition of the enclosing beds, but before the diastrophism in the area took place.

ORIGIN OF THE "BEEF".

Originally this formation consisted of marls and shales, of which the lower part contained chiefly marl in thick beds and the upper part chiefly an argillaceous marl in thin beds. The high porosity of the marls made possible the movement of the ground-water in them, and this movement, in turn, made possible the formation of the layers of "beef". The greater abundance of "beef" in the upper part of the present formation (the paper-shales) is undoubtedly the result of the greater number of bedding-planes in the original part. In accounting for the origin of the "beef", the solvent of the $CaCO_3$ of the marl, its subsequent transportation, and the cause of its redeposition as the "beef" must be explained.

The porous marl originally contained considerable water, which was largely eliminated as the marl beds were consolidated and their pore space thus reduced. As the movement of the water became slower and slower during its elimination, the minute grains of $CaCO_3$ in the marl were longer in contact with it and so passed very readily into solution as the bicarbonate. That the solutions moved toward the divisional openings in the rock is proved by the position of the "beef" layers along them and by the time of their formation. Where no movement of the water occurred recrystallization of the $CaCO_3$ with resulting induration took place.

In order to bring about the precipitation of $CaCO_3$ from the solution, it was necessary to remove the CO_2 of the bicarbonate containing it, which may have been accomplished by an increase in the temperature of the solution, a relief of pressure (CO_2 is loosely combined in the bicarbonate), or by chemical reactions. Undoubtedly, the physical factors pressure and temperature were the dominant cause of the precipitation as there is no evidence in the shales-with-" beef " that other types of solutions were present during their formation to bring about chemical reactions. Moreover, the presence of a chemically active solution would have favoured the *removal* of the $CaCO_3$ rather than its precipitation.

As the size of the openings in the marl became smaller during its consolidation the increased pressure on the solution in the openings forced it to move, where possible, toward the major divisional openings (bedding-planes) along which the movement was probably hydraulic. A slight lowering of pressure accompanied the passage of the water from the capillary spaces of the marl into the larger divisional openings. This release in pressure might have been an important factor in removing the loosely combined CO_2 and permitting the precipitation of $CaCO_3$.

We know very little about the temperature of ground-water solutions but, as essentially all spring waters have higher temperatures than those of the water in the adjacent rocks, the groundwater of the marls would certainly have had a slightly higher temperature when moving along the divisional openings than it had when it was practically stationary within the marls. If the " beef " developed at a depth of approximately 1,000 feet the temperature of the water within the marls would have been about 20° C. (a figure commonly given for the temperature of groundwater at 1,000 feet below the surface). Assuming that the temperature rose one degree when the solution reached the divisional openings, then the solubility of the contained CO_2 (according to CO_2 determinations by Bohr and Bock) would have decreased from 0·878 to 0·854 by volume. This decrease in solubility of the CO_2 would certainly have resulted in, at least, its partial liberation and the resultant precipitation of the $CaCO_3$ with which it was combined. At the lower temperatures nearer the surface the decrease in solubility of CO_2 for a one-degree change in temperature would be even greater.

Pressure and a change of temperature probably acted together in bringing about precipitation. The initial precipitation occurred on some particle of $CaCO_3$ along the bedding-plane. The removal of some of the $CaCO_3$ reduced its concentration, of course, at the point of deposition, and diffusion and further movement would result in the migration of more material to that point and the process would be repeated. The growing aggregate of $CaCO_3$ would introduce the molecular force of crystallization to further the process of deposition. This initial deposition along a bedding-plane was the beginning of a layer of " beef ". Movement of the water would be toward the plane from both sides, hence the growth of the layer was both upward and downward.

The fibrous character of the calcite layers was the result of the uniform movement of the solutions through the fine marl or shale to the plane of deposition, as Richardson has shown took place in the formation of fibrous gypsum veins.[1] Each original calcite grain received the new material only upon its exposed surface, and hence grew upward or downward, forming a fibre. Some of the original grains may have received $CaCO_3$ from both sides of the plane, but usually some of the original marl remains as a parting between the "beef" layers. This is probably due to the fact that the saturated solutions on each side of the divisional opening lost their CO_2 into it and deposition, therefore, occurred upon grains *near the edge of the opening*. A very finely-divided micaceous material which occurs on many of these parting planes may also have been a factor in preventing the solutions from crossing the bedding-planes.

As further additions of $CaCO_3$ came from the marl on either side, any of the original material left along the opening was simply enclosed by the two growing layers of calcite. A surprising feature of these parting planes is the large number of minute grains of sphalerite occurring along them.

As growth proceeded outward into the marls, the insoluble materials were pushed ahead of or incorporated in the growing calcite fibres. Variations in rate of growth of a single fibre occurred but, on the whole, the rate appears to have been very uniform. The growth of "beef" across several closely-spaced bedding-planes resulted in the inclusion of several partings within a single layer. This type is not so common, however, as the layer with a single parting. Widely spaced divisional openings in the lower division of the formation resulted in more recrystallization and consequent induration and in less formation of "beef".

Material undoubtedly moved through many inches of the porous marl to the growing fibres. Growth on the upper side of the layers was faster or continued longer than that on the lower side, as the top of the layers is the thicker. This undoubtedly was due to the dominant downward movement of the water above the plane, whereas that below tended to move downward, also, to the next layer rather than upward. Continued growth finally removed all or nearly all of the $CaCO_3$ of the adjacent parts of the marl bed, or the slow loss of CO_2 to the outgoing solutions may have stopped the solvent work and consequently any further growth of the fibrous layers.

The paper-shales, with their greater abundance of "beef" veins and divisional openings, are interpreted by the writer as having resulted from the essentially complete removal of the $CaCO_3$ of the original marls, the insoluble clayey materials having been left behind and later compacted into their present thin layers. These paper-shales contain an abundance of pyrite, which suggests deposition under, at least, slightly reducing conditions. It is probable that less $CaCO_3$ was deposited with the mud in this portion of the section. During the leaching of the $CaCO_3$ of the marl the pyrite was concentrated along with the argillaceous materials and may also have undergone some recrystallization.

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[1] W. A. Richardson, "The Fibrous Gypsum of Nottinghamshire": *Mineralogical Magazine*, xix, 1920, 77–95.

SUMMARY.

It is believed that the " beef " in the shales-with-" beef " resulted from the leaching of the $CaCO_3$ of a fine porous marl by a ground-water solution, and its subsequent redeposition. The initial redeposition was about the grains of calcite along bedding planes or similar divisional openings, and, as more material was added by the solutions moving to these planes, each original grain developed into a fibre in the layer of " beef ". Growth was from both sides, but took place faster on the upper side because the dominant movement of the water was downward. Growth stopped due to the exhaustion of the supply of $CaCO_3$ in the marl or CO_2 in the solution. The thin paper-shales between the layers of " beef " may represent the concentration of the original clay of the marl. This explanation of the origin of the " beef " would probably apply to other fibrous deposits of calcite, also.

An Unusual Occurrence of Myrmekite, and its Significance.

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(PLATE XVI.)

INTRODUCTION.

As early as 1875, Michel-Lévy made what is believed to be the first reference to that intergrowth of plagioclase and vermicular quartz which Sederholm later (1897) named " myrmekite ". In spite of its early recognition and characteristic appearance, however, there was for long no general agreement as to the geological significance or even the exact nature of the intergrowth. It appeared to be confined to the granitoid plutonic and metamorphic rocks, Becke (1913) having categorically stated that it does not occur in " *eigentlich vulcanischen Gesteine* ", so that it was with interest that the author recently (1932) recorded its occurrence in an Upper Devonian meta-toscanite from Marysville, Victoria. This does not conflict with Becke's statement, since the rock in question has suffered metamorphism by an intrusion of granodiorite, and is therefore not an " *eigentlich* " volcanic rock. Nevertheless the mode of occurrence is unique, and the history of the toscanite has been elucidated with sufficient detail to allow one to infer with some accuracy the conditions under which the myrmekite was produced. In the following account, the myrmekite, biotite-quartz-symplektite, and biotite-dactylite in the subjacent granodiorite and neighbouring adamellite bodies, as well as the myrmekite in the meta-toscanite, are described.

THE OCCURRENCE OF MYRMEKITE IN META-TOSCANITE.

The toscanite is of the Nevada type, being composed of phenocrysts of quartz, microperthite, plagioclase, and biotite, with a little cordierite, set in a microgranular groundmass of quartz, plagioclase, orthoclase, and biotite. Ilmenite, apatite, zircon and blue tourmaline are accessories.[1]

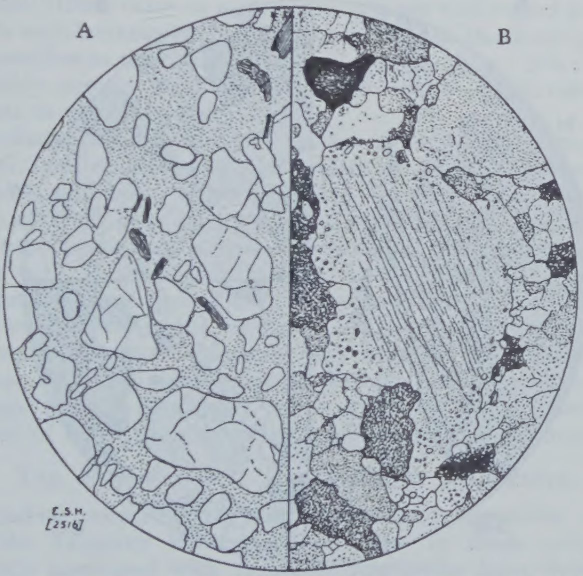

FIG. 1.—A: Meta-toscanite, Wood's Point Road, Marysville, Victoria. Slide [2516]. (× 9.) Drawn to show the proportion of phenocrysts to groundmass. B: The same. (× 21.) Crossed Nicols. Showing a crystal of orthoclase with lacinear border in a coarsely microgranular recrystallized groundmass (somewhat coarser than the normal).

During the magmatic movements antecedent to solidification, the phenocrysts suffered protoclastic shattering (Pl. XVI, Fig. 1), fragments of quartz, microperthite, and plagioclase being strewn about in the groundmass, and the biotite being twisted. In this condition the rock solidified. The broken phenocrysts now observed, however, do not show sharply defined edges, but possess what may be termed "*lacinear*" borders, which, in the case of plagioclase, contain myrmekite in certain cases (Text-fig. 2). In these borders there are included numerous rounded grains, and the boundary of the host crystal is very irregular. Quartz, biotite, and plagioclase grains occur in the microperthite ; biotite and plagioclase in the quartz ; biotite and quartz in the plagioclase, and quartz and plagioclase in the biotite (Text-figs. 1 and 2, and Pl. XVI, Fig. 3). Orthoclase grains are distinguishable with difficulty, and appear to be rare. Clearly, the problems of the genesis of the lacinear borders and of the myrmekite are one and the same, and to this we now turn.

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[1] See Hills, 1932, for a full description of this and related rock types.

Tyrrell (1926) has suggested that phenocrysts with lacinear borders may be produced by the entangling of parts of the groundmass at the end of the period of magmatic crystallization, but this explanation is difficult to apply in the present case. With the exception of the myrmekite, for instance, there are no graphic or other regular intergrowths in the borders, such as might have been expected had crystallization of the inclusions and host proceeded simultaneously ; and in the case of the plagioclase, the composition of the borders differs so markedly from that of the cores that it is clear that crystallization has not been continuous throughout (Text-figs 1 and 2).

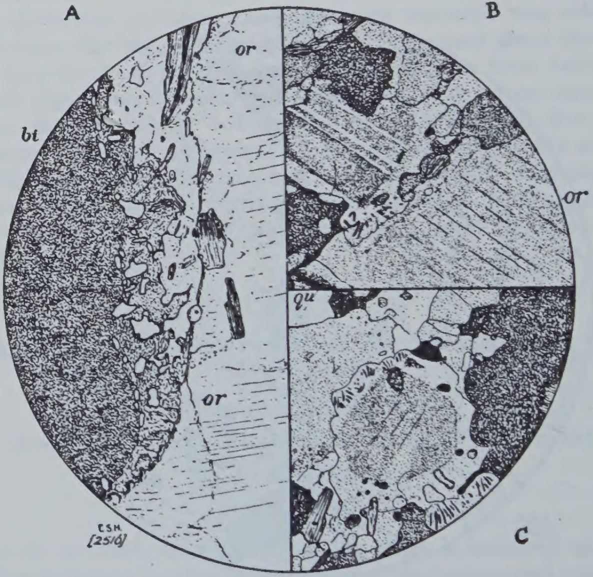

Fig. 2.—Meta-toscanite, Wood's Point Road, Marysville, Victoria. Slide [2516]. Qu, quartz ; Or, orthoclase ; Bi, biotite. A : Biotite with lacinear border. Ordinary light. (× 96.) The crystalloblastic biotite is somewhat lighter in colour than the original magmatic mineral. B and C : Illustrating the mode of occurrence of myrmekite in the meta-toscanite. Note the inclusions of mineral grains in the outer plagioclase zone, containing the myrmekite. Crossed nicols. (× 96.)

More significant still is the fact that lacinear borders are found only in lavas within the contact zones of intrusions, as in the toscanite of Wood's Point Road, Marysville [2516],[1] in the dacite of Barnwell's Track, Mt. Torbreck [2241], and in the hypersthene dacite of Plummer's Hill, Nyora [2398]. It is therefore probable that the structure developed as a result of contact metamorphism, and that the broken phenocrysts grew crystalloblastically after the solidification of the toscanite, in part replacing the groundmass, relic grains of which were left in the added borders. At the same time, the groundmass recrystallized and became coarsely microgranular. Brammall (1932) came to a similar conclusion with regard to quartz crystals with lacinear borders in xenoliths in the Dartmoor granites, for he ascribes to the borders a crystalloblastic origin. It is therefore reasonably certain that the myrmekite in the Marysville meta-toscanite is of metamorphic origin.

The changes operative in the meta-toscanite during metamorphism, however, involve essentially only additional growth of the ordinary magmatic minerals. Thus it seems that the physico-chemical conditions must have been very similar to those of the magmatic state, except that the transfer of material necessary for crystal growth went on diablastically, that is, while the rock was in the solid state. This is exactly the conclusion to which Sederholm came (1916) with respect to the conditions necessary for the development of myrmekite, and it explains why myrmekite occurs both in metamorphic rocks and in normal plutonic rocks, for in the latter late-stage phase adjustments go on in the solid state under the influence of high temperatures and in the presence of mineralizers.

THE MINERALOGICAL RELATIONS OF MYRMEKITE.

Myrmekite occurs in the granodiorite and adamellite exposed along the Taggerty River at Marysville. In these rocks it is intimately associated with dactylitic outgrowths from biotite into orthoclase (biotite-dactylite, Text-fig. 3), and with symplektites of biotite and quartz in which the latter forms vermicular inclusions in the biotite (Pl. XVI, Fig. 2; Text-fig. 3). The close association of these intergrowths has often been observed, and has generally been thought to indicate a genetic relation between them. Concerning myrmekite itself, both Becke and Sederholm believe, in brief, that the potassium of orthoclase is replaced by calcium, so that orthoclase is replaced by plagioclase, this involving release of excess silica, which forms vermicular intergrowths in the replacing plagioclase, and is the characteristic *quartz vermiculée* of myrmekite. Väyrynen (1923) has pointed out, however, that if it be assumed that the calcium ions were originally derived from plagioclase, [and in the later cooling stages of granites this must in general be the case], then Becke's hypothesis gets us no further forward, for all that is involved is a bodily replacement of orthoclase by plagioclase, during which no excess silica is produced.

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[1] Numbers in brackets [ ] refer to specimens registered in the Department of Geology, University of Melbourne.

Väyrynen suggests that myrmekite-formation follows the reaction between potash felspar and ferromagnesian minerals to give biotite and quartz, the plagioclase of myrmekite being derived from the potash felspar, in which it is present in solid solution [or perthite lamellæ]. Sederholm (1916) rejected this hypothesis because of the constant synantetic relation of myrmekite to plagioclase and potash felspar. The author would suggest that this relation may be due to the fact that the exothermic crystallization of released plagioclase, where such crystallization happens to occur adjacent to the unstable potash felspar, will facilitate the disintegration and diablastic transfer of this mineral, or of such components as are necessary for the growth of biotite elsewhere.

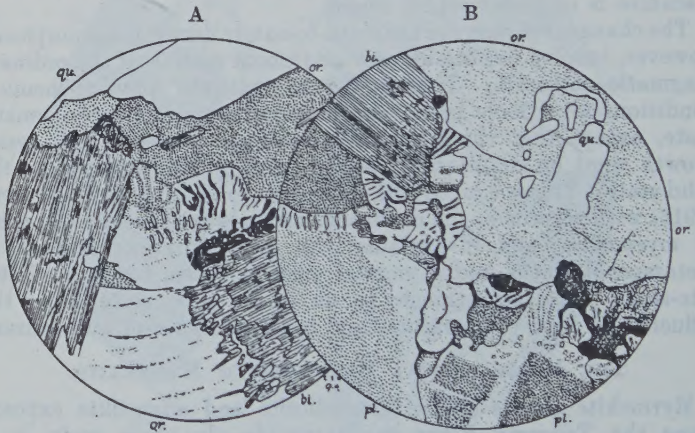

Fig. 3.—Adamellite, Keppel Falls, Marysville, Victoria. Slide [2501, *b*]. (× 90.) Qu, quartz ; Or, orthoclase ; Bi, biotite ; Pl, plagioclase. A : Shows myrmekite, crystalloblastic biotite penetrating orthoclase dactylitically, and biotite-quartz-symplektite developed on an adjacent biotite crystal. B : Shows myrmekite developed interstitially, and also in the acid borders of plagioclase crystals ; also biotite-quartz-symplektite.

Sederholm was led to consider the above hypothesis by the association of myrmekite with dactylitic growths of biotite in potash felspar in certain Swedish granites, but he concluded that the biotite-dactylite was produced crystalloblastically *after* the development of myrmekite, and as a result of the liberation of potassium ions during that process. If this be the case, the question arises why biotite should develop preferentially in potash felspar, when there are potassium ions available for its formation elsewhere ? Both Becke and Sederholm appear to have overlooked the fact that the crystalloblastic development of biotite in potash felspar necessarily releases the materials for the growth of myrmekite, and for the often associated biotite-quartz-symplektite. Their explanation does not account for its non-formation.

Moreover, it does not satisfactorily explain the observed fact, first noted by Sederholm (1916, p. 123), that myrmekite is commonest in those granites which show evidence of having assimilated basic rocks. Sederholm adduced this in support of his contention that "the formation of synantetic minerals . . . is caused, not only by an interchange of material between the neighbouring minerals, but also of materials carried in from without in solution. . . ." "Rocks rich in plagioclase," he says, "have delivered solutions rich in the constituents of this mineral, which have reacted on the minerals of the neighbouring granite rocks, resolving some of them, and in the same way the femic constituents of the basic rocks have reacted on the granitic parts, during the processes of assimilation and crystallization going on in the rock masses."

Since this was written, however, the work of Bowen has made it possible to form a truer picture of the probable nature of the reactions between magma and inclusions. Firstly, in the case of granitic magma and basic inclusions, transference (other than mechanical) of plagioclase will be not from the xenoliths to the granite, but *vice versa*, the tendency being for the acid magma to try and make over the basic plagioclase of the xenoliths to the same composition as that crystallizing from the magma. At the same time, there will be reaction with the ferromagnesian constituents of the xenoliths, such that they will be made over into the phase which is separating from or in equilibrium with the magma. In the case of granitic magma, biotite will generally be the stable ferromagnesian mineral, and biotite will develop in the xenoliths from earlier members of the discontinuous reaction series, as described by Bowen (1928). This process has been observed by many petrologists working with contaminated rocks, the recent work of Brammall (1932) on Dartmoor, Thomas and Campbell Smith (1932) at Trégastel, Wells and Wooldridge (1931) at Jersey, and more recent still, of Nockolds (1932) at Alderney, all being especially clear on the point. The development of biotite, as well as particularly good examples of the addition of sodic plagioclase to the more calcic felspar of meta-andesite xenoliths in the adamellite and granodiorite of Marysville, have already been described by the author (1932, p. 161).

Becke and Sederholm explain the development of mica at granite contacts, by assuming that the potassium ions which migrated from the granite were released during the production of myrmekite by the replacement of potash felspar by plagioclase. This view is untenable in the case of the development of biotite in xenoliths, the necessary migration of potassium ions being governed by known conditions, described above, that do not involve a preliminary development of myrmekite, and, moreover, cannot do so because the migration will be chiefly operative when the granite is in the magmatic state, when typical myrmekite does not form. If, however, the development of biotite be continued, by diablastic migration of material after the solidification of the granite, then, as has been shown above in the discussion of biotite-dactylite, myrmekite will be produced, while orthoclase is destroyed. Since in basified granites the opportunity for the development of biotite will be greater than in the case of uncontaminated rock, myrmekite will be commoner in the hybrids.

CONCLUSION.

Evidence has been adduced to show that myrmekite is produced when the physico-chemical conditions favour transfer of materials in the solid state. Thus it will be expected in normal plutonic rocks, where it develops in the paulo-post solidification cooling stages, and also in metamorphic rocks in which the physico-chemical conditions resemble those of plutonic rocks, as Sederholm has already indicated. The mineralogical relationships of the intergrowth are, however, best explained by the hypothesis put forward by Väyrynen, that it results from the crystalloblastic development of biotite from potash felspar, in which change plagioclase and quartz are liberated. This also explains the usual association of myrmekite with biotite-quartz symplektite, and with dactylitic outgrowths from biotite into potash felspar, and at the same time affords an explanation of the preferential occurrence of myrmekite in those granites which have assimilated basic rocks.

Finally, it should be noted that there seems to be a distinct difference, as yet not clearly defined, between true myrmekite and the often rather strongly developed intergrowths of quartz and idiomorphic, well-twinned plagioclase that occur in certain granites. In these intergrowths the quartz generally assumes regular geometrical forms that seem clearly to be controlled by crystallographic forces, and bear only a slight resemblance to the truly vermicular, radiating rods of myrmekite.

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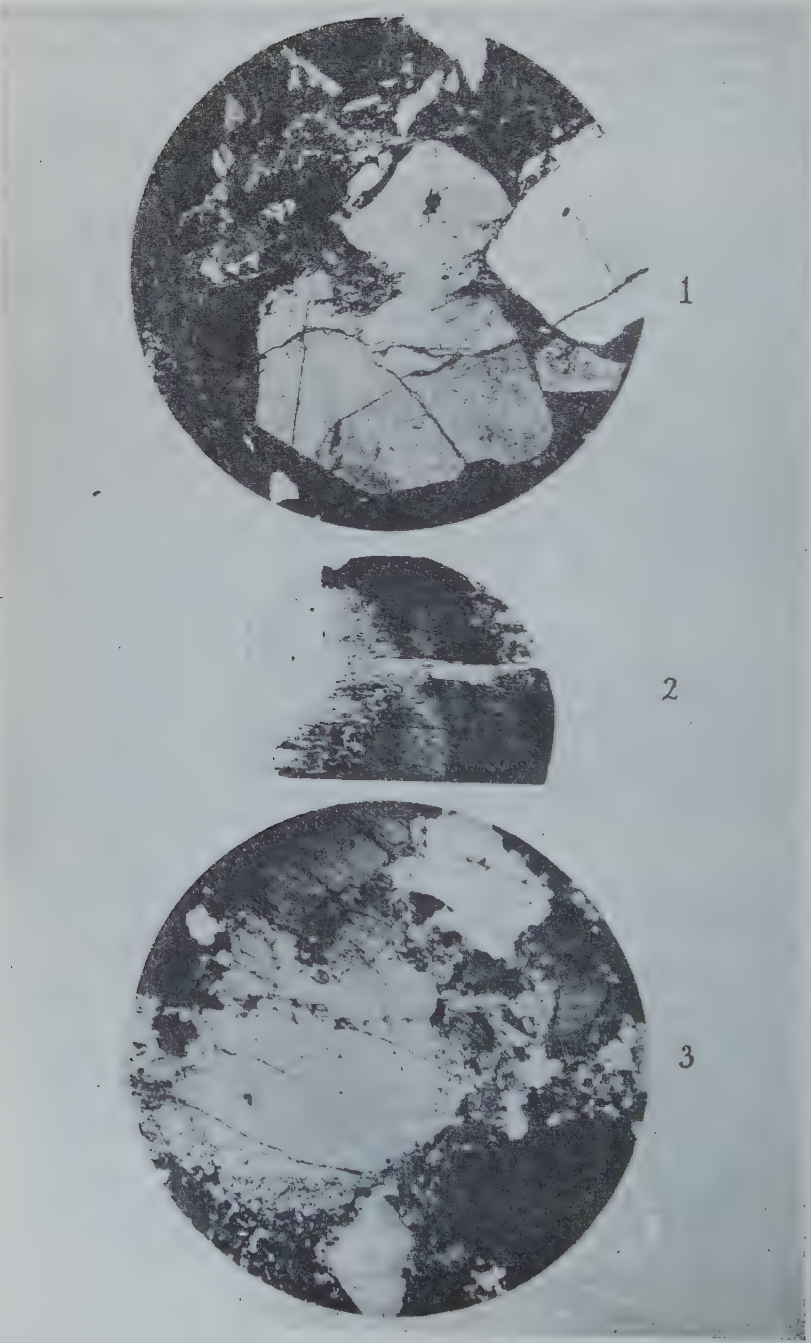

MYRMEKITE AND OTHER STRUCTURES IN ROCKS FROM VICTORIA.

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EXPLANATION OF PLATE XVI.

FIG.

1.—Protoclastic shearing of quartz phenocrysts in nevadite, Taggerty, Victoria. Slide [2244]. (× 25.) Crossed Nicols. This slide clearly shows that the shearing stresses were transmitted through the meshwork of phenocrysts, after the embayment of the quartz and before the solidification of the rock. It was round the crystal fragments so produced that lacinear borders were subsequently developed in certain of the lavas.

2.—Biotite-quartz symplektite in adamellite, Keppel Falls, Marysville, Victoria. Slide [2501, *b*]. (× 100.) Ordinary light. The symplektite is seen to be developed on faces in the zone parallel to the vertical crystallographic axis.

3.—Phenocryst of orthoclase with lacinear border, in meta-toscanite, Talbot Drive, Marysville, Victoria. Close to the granodiorite contact. Slide [2517]. (× 25.) Crossed Nicols. The early idiomorphic crystal boundary can readily be distinguished within the lacinear border.

Lower Tertiary Rocks in the Province of Berber, Anglo-Egyptian Sudan.

By K. S. SANDFORD.

IN the Abstracts of the *Proceedings of the Geological Society of London*, No. 1254, of 16th December, 1932, Mr. L. R. Cox described certain siliceous boulders, and their Lower Tertiary fauna, collected for the most part at Hudi, north of the Atbara, by Mr. G. V. Colchester and others. As Mr. Grabham pointed out, the implications that the nature of the boulders and their fauna involve are of supreme importance to the geology of this part of the Nile Basin and, for that matter, of Africa.

A few days before Mr. Cox read his paper I received a message at Ed Damer[1] from Mr. Grabham suggesting that a visit should be paid to the district of Zeidab, on the west side of the Nile about fifteen miles south of Ed Damer, where similar rocks had been recorded. Thanks to the kindness of Mr. E. S. Fiddes, Deputy Governor of Berber, and of Mr. Harvey at Zeidab, this was done. The visit was purely a reconnaissance, made possible by Mr. Harvey's willingness to take his car over some very rough country, and detailed investigation is to be desired. At the present juncture, however, the results seem to be worth placing on record.

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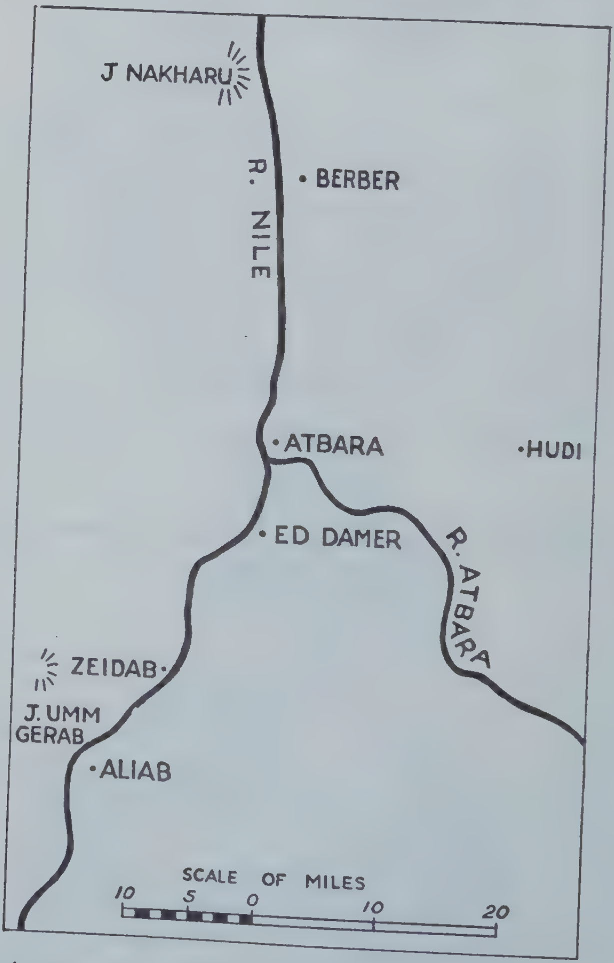
[1] Provincial headquarters of Berber Province.

On leaving the cultivated land adjacent to the Nile we passed over old alluvium and gravel on to surfaces which may be suitably described as fields of 'Hudi-stone'. They are overlapped locally by the old alluvia (found elsewhere to be of Palaeolithic age): they mark very slight hollows in the surface of the underlying Nubian Sandstone. The stone is not in the form of scattered boulders, as at Hudi, but seems to have broken up *in situ* into angular fragments like road metal: indubitably water-worn boulders were not observed, but some projecting masses are wind abraded. The stone is of precisely



the same texture as that of Hudi, and fragments collected there at a later date can be distinguished from the Zeidab specimens only by their labels. Comminuted shell fragments are present, so is the remarkable petrological constitution described by Mr. Cox.

It seems probable, therefore, that in the desert west of Zeidab the original surface and its Lower Tertiary covering reduced to thin skins have both been partially preserved intact: the district may prove on further investigation to possess advantages for study which are lacking at the type locality, Hudi, where the boulders may have been transported from a distance.

Very different is the appearance of the country above and west of this low plain, for it is broken and rugged, wind-blown and dissected by many stream beds and wadies. Its edge is marked by a long line of cliffs, standing about 75-100 feet above the plain in this neighbourhood but rising to greater heights nearby, broken here and there by wadies.[1] Scarp and dissected plateau reveal false-bedded brown and buff sandstones with quartz pebbles, which also form the flat floor of the plain on which the Tertiary rocks lie. There seems to be no doubt whatsoever that the sandstones are totally distinct from the fossiliferous rocks and of far greater age: they are also typical of thousands of square miles of Nubian Sandstone, to which series they unquestionably belong. In this district, then, we are relieved from any necessity of suspecting that the sandstone, so long regarded as of Mesozoic or even greater age, may be a Lower Tertiary deposit: there is no confusion of the Tertiary rocks with the bedding of adjacent and subjacent strata.

The foregoing conclusion is emphasized by the discovery at the foot of the scarp and on its lower slopes of considerable masses of extremely hard quartz-pebble conglomerate, evidently more or less *in situ*, closely resembling ferruginous and siliceous pebble beds that are common in the Nubian series. The pebbles are certainly derived therefrom but they are bound up with fragments of fossiliferous Hudi-stone. In the field they suggest a lateral accumulation akin to the siliceous deposits of the Lower Tertiary lake (if such it was), but evidently somewhat later than the initial formation since the Hudi-stone had become silicified before incorporation in the pebble bed.

It may be some comfort to those who now suspect the pre-Tertiary age of little or much of the Nubian Sandstone to learn that, although Mr. Grabham had told me of the new problem and Mr. Cox had kindly allowed me to read the draft of his paper in the summer of 1932, I found not a single trace of Hudi-stone or similar deposits

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[1] The plain was crossed from the headquarters of Zeidab plantations westward to the scarp at a point called by local Bedouin Jebel Umm Gema, which appears to be identical with J. Umm Gerab (see Survey Dept. 1 : 250,000 map sheet 45–K). The line of hills recalls the scarp culminating in J. Nakharu, 9 miles N.N.W. of Berber town, where the Tertiary rocks are also reported to occur.

—despite purposeful search—during a recent tour of the central and southern Libyan desert, almost entirely over Nubian Sandstone.[1]

Important unconformities there certainly are in this wide area, as I shall hope to show at a later date, but I know of nothing in any way analogous to the Hudi-Zeidab Lower Tertiary rocks, and offer the suggestion that these will be found to be limited to the environs of the Nile valley and of certain of its major tributaries, like the Atbara. In such districts, as shown in Mr. Cox's paper (*ibid.*, p. 18) and above, redeposited Nubian Sandstone may closely resemble the original, but such similarity need not cause us to doubt the age of the older beds.

In the same district of Zeidab, but on the east side of the Nile as far south as Aliab, irregular boulders, sometimes collected in small piles, may be seen on the cultivated alluvium. Some at least were of Hudi-Zeidab rock and had no doubt been brought short distances from the desert edge for a variety of domestic purposes : others, in little heaps, suggested small outcrops projecting through the alluvium but we saw none scattered over the fields like flints on chalky ground.

Mr. Grabham, in his comments on Mr. Cox's paper (*ibid.*), has referred to the presence of Hudi-stone in old Nile gravels north of the Atbara as far as Wadi Halfa : it may be found also in such gravels as far south as Ed Damer at any rate. This, with the outcrops at Zeidab, indicates an extension of the known area considerably to the south of the Atbara, which had been regarded as its southern limit. North of the Atbara the Nile gravels are in large measure composed of the rock for many miles, and even in Dongola, in a region of granite and Nubian Sandstone, its presence in old alluvia serves to distinguish Nilotic from local deposits which would otherwise be almost indistinguishable one from the other.

In making these observations, which were complementary to other geological work, my wife and I were greatly helped by facilities granted us by the Sudan Government, to whom our thanks are due. The perpetual *deus ex machina* of this and other work is Mr. Grabham, Government Geologist. It is hoped that these and other results will be of technical, if not also of economic, utility within the country.

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[1] An expedition led by Major R. A. Bagnold. See a paper read before the Royal Geographical Society on 29th May, 1933.

On an Area of Ultrabasic Rocks in the Kassala Province of the Anglo-Egyptian Sudan.

By W. H. Wilcockson, M.A., F.G.S.,
and W. H. Tyler, M.Sc., F.G.S.

(PLATE XVII.)

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INTRODUCTION.

THE following article is an account of an area of some 1,000 square miles in the Anglo-Egyptian Sudan, crossed by latitude 13·30 N. and longitude 35·00 E. which was surveyed on the 1/50,000 scale during the years 1930 to 1932 by W. H. Tyler, who has published a brief note on the general geology (13).[1] W. H. Wilcockson is responsible for the petrology.

The Kassala branch of the Sudan Government Railway crosses the northern part of the region, and the railway station of Qala en Nahl, some 500 miles from Port Sudan, lies close to the largest mass of hills in the area.

An outline of the geology of the country is as follows. The oldest rocks are a series of altered sediments referred to as the basal schists, a series of schists and phyllites with, in three localities, a thin band of marble. Basic and ultrabasic rocks, now represented by altered gabbros, serpentines, talc-carbonate and quartz-carbonate rocks are the oldest intrusive rocks and appear to have penetrated the basal schists. In the west many hills of granite, both large and small, are seen and granite also outcrops to the east of the serpentine rocks as a dyke-like body. In the south-east a large mass of rock varying in composition from diorite to gabbro was intruded at a later date. By far the larger part of the area is covered by a thick deposit of black cotton soil of recent origin which, where present, completely hides all the rock outcrops, making any interpretation of the general

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[1] Figures in parentheses refer to Bibliography at the end of this article.

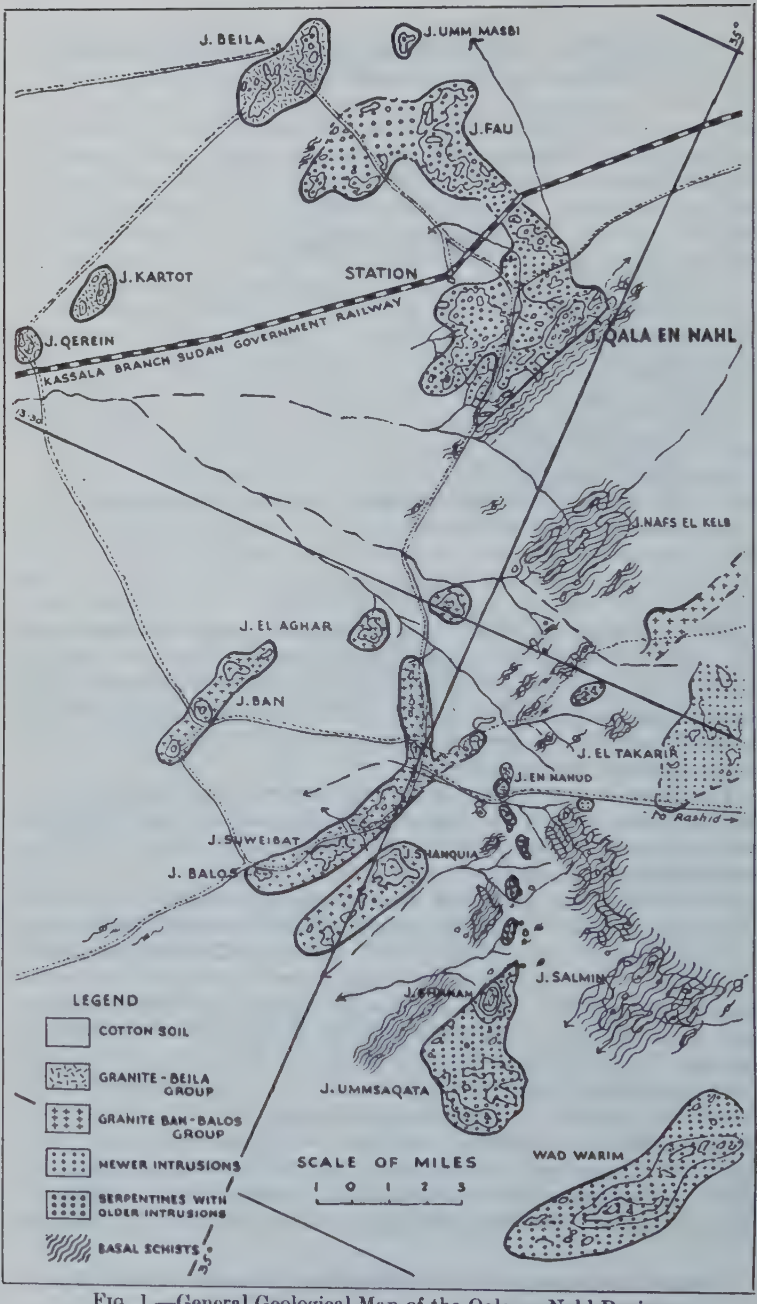

Fig. 1.—General Geological Map of the Qala en Nahl Region.

structure of the country merely speculative. The accompanying maps show the general distribution of the rock types.

INTER-RELATIONSHIPS OF THE OUTCROPPING ROCK MASSES.

The average strike of the foliation of the basal schists is between 20 and 30 degrees east of north in the undisturbed areas. This can be well seen round Jebel Nafs el Kelb. The strike of the foliation of the talc-carbonate rock within the ultrabasic intrusions is also about the same and this direction seems to be of first importance in the whole region. The Qerein-Kartot-Beila hills in the north-west, which, as will appear later, are probably the outcrop of one large granite mass, are aligned in the north-north-east direction, as are also the granite hills of the south-west. The Balos-Suweibat granite mass in the latter area, which is probably connected underground to the similar intrusion east of Nafs el Kelb, forms a body whose long axis lies on a line 30 degrees east of north, whilst the Ban-Aghar mass and the Shanqiya mass are parallel to it. The straight junction between the serpentine and basal schists at the east side of the Qala en Nahl hills is marked by a strong quartz reef with a similar strike, and the junction between these same two rock types on the west side of Jebel Ghanam is again a straight line running 20 degrees east of north. The serpentine hill of Wad Warim is a long ridge with a strike of about 30 degrees east of north.

It seems clear from the above evidence that the whole region has been subjected to pressure acting in a direction at right angles to this common north-north-east strike and that the plutonic rocks rose along movement planes parallel to the strike.

A line of serpentine hills also runs in a direction some 25 degrees west of north from Jebel Ghanam to Jebel Nahud. Between the Balos-Suweibat granite and the Ban-Aghar granite is a line of small granite hills running 30 degrees west of north which possibly connect the two north-north-east striking masses. The Fau hills of serpentine to the north-west of Qala en Nahl have a long axis which strikes at 40 degrees west of north. This suggests a secondary series of movement planes up which also plutonic rocks have risen.

The fact that the earliest groups of intrusions, i.e. the serpentines, follow both these directions suggests that both had been impressed on the country at a very early date ; whilst the fact that the foliation of the talc-carbonate rocks, which were originally part of the serpentine intrusions, is parallel to that of the basal schists suggests that pressure at right angles to the north-north-easterly direction was exerted again later than the ultrabasic intrusive phase. The small mass of serpentine to the north-east of Jebel en Nahud and south-east of Jebel Nafs el Kelb may originally have belonged to the north end of the Ghanam-Nahud serpentine, from which it has been separated by movement along a plane associated with the line of intrusion of the Balos-Suweibat-Nafs el Kelb granite.

The succession of events appears to have been as follows :—

(7) Deposition of Cotton Soil.
(6) Newer Intrusions (diorites and gabbros).
(5) Intrusion of Ban-Balos Granites accompanied by quartz reefs and silicification of the serpentines.
(4) Foliation of the Country.
(3) Intrusion of the Beila Granite with serpentinization followed by carbonation of the ultrabasic rocks.
(2) Intrusion of the Ultrabasic Rocks and Older Gabbros.
(1) Deposition of the Basal Schists.

Basal Schists.

The chlorite schists are green quartz-chlorite rocks with occasionally some epidote and in places calcite and cordierite. The sericite schists are well foliated quartz-sericite rocks usually containing some magnetite or hæmatite. There are many outcrops of quartzose rocks. Some of these are certainly quartz veins which lie along the planes of schistosity, but others appear to be quartzites ; of the latter there are two types, (A) compact white almost pure quartz-rocks and (B) black magnetite-quartz-rocks which may have an origin similar to that of the banded ironstones of other crystalline areas. Limestones are rare among the exposed schists. One thin bed of dark banded marble occurs on the north-west slopes of Jebel Ghanam and another at the extreme north-east end of the Qala en Nahl hills ; at Nafs el Kelb a large mass of coarsely crystalline calcite is infolded among the schists and may also represent a limestone. In the west, between Qala en Nahl and Beila, there are platy coarsely crystalline hornblende-schists composed of quartz and a hornblende with pleochroism from green to blue, which is probably sodic. One slice, rich in quartz, contains well developed pink garnets.

Serpentines.

The normal serpentine of the country is a massive green rock, sometimes dark and fresh-looking and elsewhere speckled with dark or light patches. At widely scattered localities the rock assumes an earthy appearance, is biscuit-coloured, and has irregular veinlets of iron ore. Along the contacts of the talc-carbonate masses, the serpentine, for a short distance, appears to be drawn out into fingers alternating with talc-carbonate rock. Many of the apparently massive serpentines show foliation in thin section. The normal serpentine is probably an altered dunite and a few specimens which have escaped excessive pressure have the ordinary mesh structure of altered olivine outlined in magnetite grains (Pl. XVII, Fig. 1). In several specimens irregular patches, seen under the microscope, have fibrous structure suggestive of bastite, and at two localities serpentinized olivine is enclosed poecilitically by well developed bastite. Most of the serpentine has now the habit of antigorite. This mineral may be seen developing even in those specimens in which the mesh structure still remains, but in most specimens collected the olivine structure has been entirely obliterated. The antigorite may occur as spiny flakes of varying size and intercrossing almost at right angles, a type which has been referred to as "thorn structure" (2, p. 702) (Pl. XVII, Fig. 3), or with the chequered pattern called "gestrickte Struktur" (2, p. 700) (Pl. XVII, Fig. 4), in which large feathery crystals of antigorite form the sides of the squares and enclose a fine-grained serpentine with low double refraction. In other specimens, particularly near the areas of talc-carbonate rock, the antigorite flakes have a parallel arrangement and give a foliated appearance to the rock. Talc is uncommon in the normal serpentine and has only been observed in two specimens in which it occurs as white flakes in a green rock. A yellow flaky mineral is often associated with the ores; it occurs either as irregular patches or intergrown with antigorite and magnetite. In ordinary light it looks like stained serpentine, but between crossed nicols, it is seen to have an exceedingly low double refraction.

OPAQUE CONSTITUENTS.

In addition to the magnetite along the meshes of the olivine pseudomorphs, these occur as rounded grains and as intergrowths with the antigorite flakes, the so-called "ophitic magnetite" (2, p. 702). This last type is of late secondary origin and is very fine-grained. Most of the grains of ore are opaque and are probably magnetite, but some few are translucent, showing red or brown on the edges, and may be chromite or picotite. Chromite occurs frequently as rounded grains which are black by reflected light and red by transmitted light, and often have a border of material which is opaque and gives a grey-black colour in reflected light. This opaque material also occurs as veinlets inside the grains. Many of these grains are magnetic and it is possible that, as suggested by Dresser (3, p. 76), the opaque portions are high in iron. Some large specimens of iron ore, occurring as lenses in the serpentine, show magnetic polarity, but give a decided reaction for chromium. Such zoned chrome-iron ore grains have been described by several authors, and the suggestion has been made that the opaque outer margin may be due to the outward migration of Al_2O_3, which shows itself as chlorite in the surrounding rock (7, p. 640). In the serpentine slices no chlorite has been observed and the relation would appear to be one of intergrowth as suggested by Phillips (7, p. 640). However, chromite occurs also as bodies of high-grade ore with lens-shaped outcrops in both serpentine and talc-carbonate rocks. In these a very small amount of chlorite has been observed in narrow serpentine-filled partings in the chromite. The chromite has the same microscopic appearance as it has in the serpentine and contains a considerable quantity of the opaque material. If the opaque material is an indication of the outward migration of alumina, then there should be around it a much greater quantity of chlorite than actually occurs. Although the hand specimens of chromite have a mauve colour which has been attributed to the mineral kämmererite (7, p. 639), no kämmererite has been identified and the chlorite has the optical properties of penninite.

Bands of chlorite-schist up to 3 feet in width traverse the serpentine in many places. The chlorite is green and exhibits pleochroism from pink to bluish-green. It has a fairly high double refraction and is of the clinochlore variety.

Chrysotile asbestos is found in the serpentine at several localities in irregularly shaped zones which have no systematic distribution.

CARBONATION.

Carbonates occur in almost all specimens of serpentine which have been examined. They are all subsequent to the serpentinization of the rock. One rock from a place to the north of Jebel Ghanam has many lines of iron-ore granules developed in cracks from which carbonate crystals have grown outwards and replaced the flakes of the antigorite, as though the cracks had acted as passages for the solutions. In the neighbourhood of these cracks the flakes of antigorite are larger than usual. In rocks where the mesh structure is not destroyed the carbonation seems to have followed the cracks of the olivine and to have spread from these (Pl. XVII, Fig. 1). Where no mesh structure remains the carbonate is in irregular patches. Small granules of carbonate began to grow both between and inside the antigorite flakes; neighbouring granules coalesced in crystalline continuity, and, when the serpentine was entirely replaced, formed crystals with well-developed cleavage in the interior but with irregular granular edges which betray their origin.

In addition to the spathic carbonates just described, the white porcellanous variety of magnesite occurs in narrow fissures in the serpentine, but is only abundant to the west of the Qala en Nahl range.

TALC-CARBONATE ROCKS.

The outcrops of the talc-carbonate rocks appear on the map as irregular lenses of varying size (Fig. 2). The largest known mass is situated in the west of the Qala en Nahl hills and is about 2 miles long and three-quarters of a mile wide, but most of them are smaller and some are only a few feet long. The boundaries are slickensided and along the borders of the large lenses the serpentine and talc-carbonate rock alternate in interpenetrating fingers lying parallel with the contact. In places small isolated lenses are found beyond the ends of these fingers as though they had been torn from them. The talc-carbonate rock is itself foliated and occurs in solid bands of very variable width separated by narrow schistose partings parallel to the length of the lenses. The solid portions weather into large slabs with shining faces parallel to the schistosity. Carbonates form elongated grains up to one quarter of an inch in length which, when broken out by crushing, are seen to be the

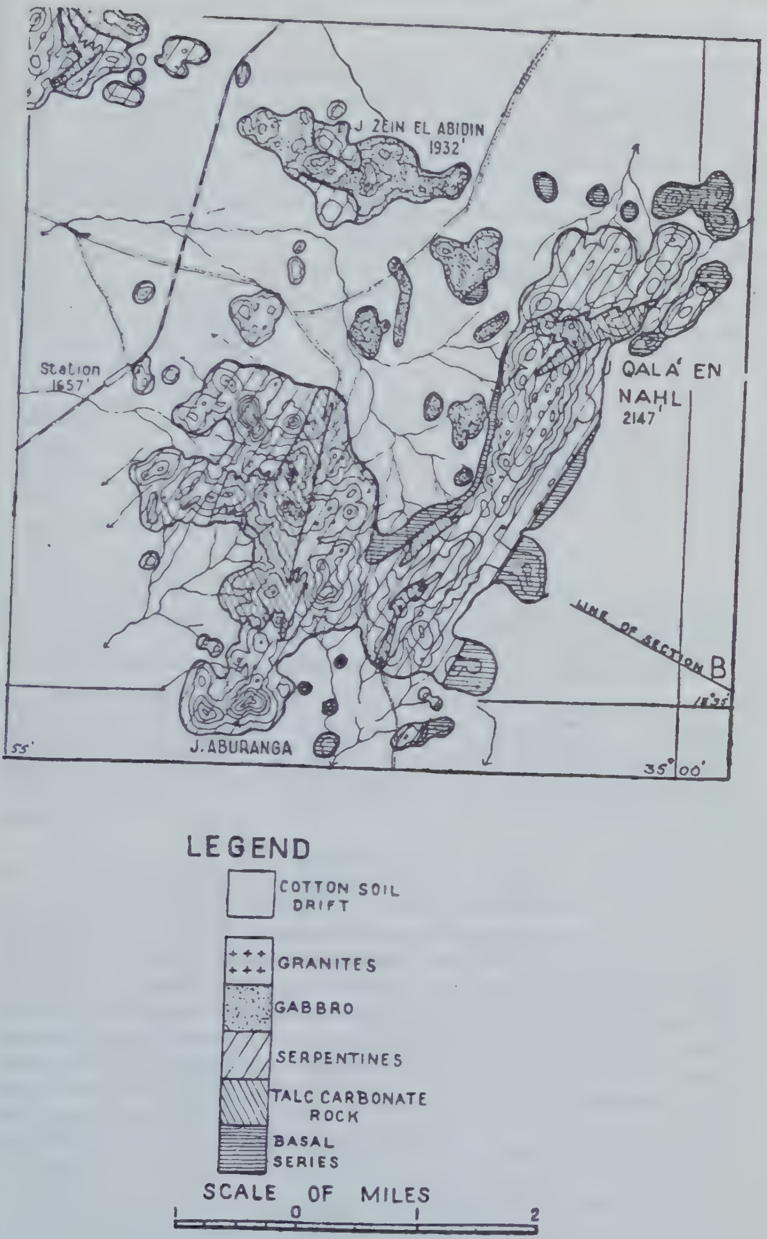

Fig. 2.—Map of the Qala en Nahl Hills.

cores of augen. The rock is pale green or cream, and turns brown on weathering. Under the microscope it shows a sugary mass of small rounded carbonate grains separated by sheaves of talc fibres with a parallel arrangement and a few patches of serpentine (Pl. XVII, Fig. 2). Opaque ore occurs in irregular grains of varying size; the grains are black in reflected light and the edges of some of the smaller ones show a brown colour in transmitted light. Analysis shows that much of the ore contains chromium, many grains are magnetic, and it is probable that both chromite and magnetite are present.

The analysis of the rock is given below:—

	(1)	(2)
SiO_2 . . .	20·16	31·43
TiO_2 . . .	*nil*	*nil*
Al_2O_3 . . .	2·27	2·53
Cr_2O_3 . . .	0·89	0·37
FeO . . .	6·85	4·50
CaO . . .	0·30	0·37
MgO . . .	36·35	35·44
Alkalies . .	not det.	not det.
Loss on ignition .	33·60	24·60
Total . .	100·52	99·24

Anal.: W. H. Tyler.

(1) Piece of rock from surface at extreme north-east end of the largest talc-carbonate lens.

(2) Average sample of talc-carbonate rock from an adit in the main body of the same lens.

NOTE.—The rocks analysed were obtained from the oxidized zone.

In such rocks the iron is not necessarily in its original state of oxidation and the whole of the iron is therefore given as FeO.

These analyses, in conjunction with the observations of many thin sections, show that the mineralogical composition of the rocks is approximately as follows:—

	(1)	(2)
Talc . . .	33·00%	49·00%
Magnesite . .	55·00%	42·00%
Other constituents	12·00%	9·00%

The carbonate granules of the rock turn dark brown on weathering, which suggests, when considered in conjunction with the lime and iron content of the rock, that it is near to breunnerite.

Macgregor reports (11, p. 24) that in similar rocks from Southern Rhodesia the combined water is only 0·8 per cent, and suggests that the magnesian silicate is largely anthophyllite. Separate estimations of the CO_2 content of the rocks (1) and (2) give 28 and 18·7 per cent respectively, which leaves 5·6 per cent combined water in No. 1 and 5·9 per cent in No. 2. The percentage of combined water in these rocks therefore is more than sufficient for the talc shown in the approximate compositions above. The balance is in part accounted for by the small quantities of serpentine observed in the slices and at any rate there is no need to assume that any of the fibrous mineral is anthophyllite.

QUARTZ-CARBONATE ROCKS.

All the large masses of talc-carbonate rock have a core of quartz-carbonate rock along practically the whole length near their centre line. The major portion of this rock is a fine-grained mixture of quartz and carbonate, but the weathered surface sometimes shows a filigree of narrow quartz stringers standing out above a smooth weathered surface. The cores pinch and swell, varying in width from a few inches up to 20 feet. Under the microscope, the core from the largest lens of talc-carbonate rock shows large well-formed crystals of carbonate with interstitial masses of quartz. Talc occurs as aggregates of very small fibres between the crystals of the other minerals and inside the quartz. There is a little opaque material in fine grains mostly in the carbonate. The quartz shows some strain effects, but the carbonate is almost entirely untwinned. The relative age of the carbonate and the quartz is not obvious, the carbonate occurring in well-formed rhomb-shaped crystals in the quartz, but sometimes the edges of the carbonate crystals are irregular. However, the existence of the quartz filigree suggests that this mineral was introduced last, as has been shown to be the case in similar rocks at Que-Que in Southern Rhodesia (10, p. 19).

SILICIFICATION.

Silicification has affected the serpentine at three localities, to the south-west of Qala en Nahl, on Jebel Ghanam, and at Jebel Fau. This alteration has a different character from the formation of quartz-carbonate rock and takes the form of a complete substitution of the silicate minerals by quartz or chalcedony, sometimes with the production of drusy cavities lined with quartz crystals. No talc or carbonate has been formed and the magnesia has been totally removed. The iron ores are not attacked. At Jebel Fau the silicification has taken place over an irregular area, but at Ghanam and in the south-west of the Qala en Nahl hills the replacement follows a line parallel to the strike of the country. At the latter place the silicification occurs in a band 50 feet or more in width forming the top of a hill into the base of which a quartz vein can be seen to pass. On the plain close to the hill the vein is a wide single quartz-filled fissure. At the base of the hill it has split into two veins, cutting unsilicified serpentine. Near the top of the hill it disappears and its place is taken by the band of silicified serpentine along the same strike and forming a capping to the hill. Apparently when an open fissure was no longer available, the siliceous solutions filtered on through the serpentine and replaced the silicate minerals. These rocks seem similar to the silicified dunites which have been called birbirite (8, p. 137).

THE OLDER INTRUSIONS.

In the northern part of the Qala en Nahl hills, and east and south of Jebel Ghanam, there are intrusions of highly altered gabbros.

They are usually in contact with the serpentine, but their boundaries are always obscured and no age relations have been established. In hand specimens they present a green and white mottled appearance. The size of the constituent crystals is usually about an eighth of an inch, but in the Fau hills there is a ridge composed of a coarse-grained variety with crystals up to 1 inch and over in length. Clearly the rocks are highly altered. The felspar is replaced by a dull-white material of hardness 7 which suggests silicification and the whole rock is extremely tough. Under the microscope the rocks have the structure of gabbros. In two specimens the ferro-magnesian mineral has been augite and retains diallage structure, but most of the pyroxene has been altered to an amphibole similar to actinolite and to serpentine. The actinolite occurs in two forms, first as an aggregate of small interlacing blades forming borders to unaltered pyroxene crystals and along shear zones in them, and secondly as veinlets in which the amphibole crystals lie at right angles to the walls after the manner of asbestos. The borders are most commonly formed where the augite was in contact with the felspar. The amphibole is very pale olive-green with extinction up to 18 degrees and therefore near to tremolite. The unsheared centres of the pyroxene crystals are often altered to serpentine, and this mineral also occurs as irregular patches in the felspar. In the coarse-grained rock of the Fau hills the augite was almost entirely replaced by an olive-green amphibole, for the most part in homogeneous crystals. This amphibole includes some serpentine in patches and as veinlets along the cleavage planes. The felspar is always represented by a saussuritic aggregate, consisting of many small crystals of zoisite in a groundmass of quartz. In the Fau rock the saussuritic aggregate contains long needles of secondary amphibole. There in no carbonate or iron ore in the specimens which were collected. These older gabbros are only found closely associated with the serpentine masses (Fig. 2), and this proximity, coupled with their general altered and crushed condition, suggests a similar age, though in this case the absence of carbonate is curious.

THE WESTERN GRANITES.

These form two chief intrusions or groups of intrusions, those of the Ban-Balos area in the south-west and those of the Beila area in the north-west. The Ban-Balos group are microcline-granites, composed essentially of microcline and subsidary plagioclase of albite-oligoclase composition, and little or no orthoclase. The most common ferro-magnesian mineral is biotite with a little muscovite and at one locality some hornblende with bluish-green to yellowish-green pleochroism. Accessory minerals are rare, the only ones noticed being magnetite and very few crystals of zircon. In one specimen from Jebel Balos the mica cleavages are bent and the microcline is traversed by crush veins, but the rocks as a whole are not foliated.

In the north-western district, Jebel Beila and the neighbouring hills are composed of foliated granophyric granites. The Qerein-Kartot group of hills between Beila and the railway are of a gneissic type of granite with a marked parallel arrangement of the mica-flakes, whilst the Beila mass is very coarse and pegmatitic. The felspar in these rocks is mainly a plagioclase with nearly straight extinction, associated with microcline and some orthoclase. Both the plagioclase and microcline frequently exhibit perthitic structure. Quartz-felspar intergrowths are characteristic of this granite group. The intergrowths are both on a fairly large scale and on a small scale in which the quartz content has a vermicular habit resembling myrmekite. The ferro-magnesian mineral is a brown strongly pleochroic biotite and at Qerein, there is hornblende with blue-green to brownish-green pleochroism. At Beila the pegmatites contain a dark epidote resembling allanite (4).

East of Nafs el Kelb there is an isolated mass of granite. This rock does not form upstanding hills as do the granites in the south-west. It is a pink rock and rather altered. Its felspar includes both microcline and plagioclase, the latter being dominant. The ferro-magnesian minerals are brown biotite and hornblende with pleochroism from green to yellowish-brown. The biotite is mostly altered to green chlorite, but the hornblende is almost entirely fresh. The only accessory mineral is sphene, which is abundant in large well-formed crystals. The felspar is mostly replaced by sericitic aggregates and there is some brown epidote in fairly large grains. The rock has no trace of foliation and appears to be related to the granites of the south-west.

Both the Beila and Ban-Balos granites are newer than the serpentine. To the south-west of Jebel Fau the serpentine is cut by dykes of pegmatite associated with the Beila granite, since they contain the characteristic dark epidote. The serpentine is also cut by quartz veins associated with the Ban-Balos granites. The Beila granite, being foliated, is probably older than the Ban-Balos granites, which have not been affected by the foliation.

Metamorphic Rocks Associated with the Western Granites.

Although all contacts of the large granite masses are obscured by the cotton soil, three fragments of rock collected from the foot of the granite hills of Jebels es Suweibat, el 'Aghar, and Kartot, have the appearance of thermally altered basal schists. The rock from Jebel es Suweibat is a fine-grained granulite composed of quartz and a plagioclase, with nearly straight extinction, in small rounded grains, green biotite in small flakes, and a little bluish-green hornblende. There is much scattered magnetite in very small granules, and apatite is abundant in rather irregular elongated crystals and minute needles. Brownish epidote occurs as irregular grains. This rock may come from close to the contact or may be a xenolith of igneous rock somewhat more basic than the granite. The metamorphic rock associated with the el 'Aghar granite is similar to that from es Suweibat but coarser grained, and contains abundant green actinolite in blades and needles in place of biotite. The Kartot specimen is essentially an epidote-quartz rock with some colourless augite, chlorite, and a little apatite. In places blades of bluish-green actinolite have grown in the epidote. Close to a quartz vein which traverses the slice are irregular crystals of scapolite with incipient alteration following the cleavages and showing, between crossed nicols, the watered appearance which has been attributed to variation in the lime content of the mineral (12, p. 502).

Newer Intrusions.

East of the central area is a group of hills, the largest of which is called Jebel Qala et Takarir, composed of basic rocks much fresher than the older gabbros. The major portion of the mass is a normal gabbro composed of basic labradorite and diallagic augite. The augite is colourless with well-developed diallage and occasionally sahlite structure. Many crystals have developed rims of brown hornblende and in places are altered to irregular aggregates of tremolite associated with chlorite, abundant grains of iron ore, and a mineral resembling talc. Similar aggregates also occur, having no apparent connection with augite crystals when they exhibit concentric structure. The felspar is very fresh, but some crystals show chlorite flakes developing along the cleavage planes and throughout the crystals near their contacts with the tremolite aggregates. One specimen shows a junction with a hornblende granulite with shear zones, accompanied by carbonation, running parallel with the contact.

Associated with the main mass of the gabbro is a rugged hill made up of a mottled coarse-grained rock. Under the microscope this rock is seen to contain a large proportion of hornblende with interstitial felspar. The hornblende is pleochroic in shades of brown and is altered at the edges of the crystals to chlorite. It contains no remnants of augite but has abundant parallel schiller inclusions suggestive of an original diallage structure and is probably secondary. The felspar is similar to that of the normal gabbro, but in places is altered to a saussuritic aggregate containing some zoisite and secondary quartz. On the Rashid road, about 2 miles south of the main mass, is a small outcrop of hypersthene-gabbro. Both orthorhombic and monoclinic pyroxene are present as kernels in large crystals of secondary hornblende with brown to green pleochroism. In most cases the hornblende directly encloses the hypersthene, but in some places an intermediate zone of monoclinic pyroxene shows that the alteration to hornblende has followed the normal discontinuous reaction series hypersthene-augite-hornblende. The felspar is fresh and similar to that of the other gabbros except that it is finer in grain. As accessory minerals, apatite is abundant in large crystals and there is some magnetite.

About 3 miles west of the outcrop of the hypersthene-gabbro is a small isolated knob of ultrabasic rock. This is a normal hornblende-picrite containing well-formed crystals of augite, often enclosed in large plates of brown hornblende and in places altering to brown hornblende. Felspar is present as interstitial patches, now entirely altered to opaque saussuritic aggregates.

These rocks are apparently a related series and, from their appearance, are newer than the other basic intrusions, though there in no evidence of their age relation with the granites.

OTHER IGNEOUS ROCKS.

Dykes of basalt and dolerite are seen in several places in the eastern part of the area, and at Sim-Sim in the south-east is an isolated hill of fresh riebeckite-trachyte, which is apparently an intrusion. One of the basalts cutting the basal schists is a porphyritic spilite and at Qala en Nahl loose blocks of a very basic rock resembling limburgite are found on the surface of the serpentine outcrops.

THE GENESIS OF THE SERPENTINE AND THE TALC-CARBONATE ROCKS.

Where the original structures of the ultrabasic rocks survive there is no evidence that they were other than plutonic. On the subject of the origin of serpentine many different views have been advanced; some authors (7, p. 648; 5) have suggested that the action was one of autometamorphism and that the active solutions had their origin in the ultrabasic magmas themselves. The recent work of Keep on a series of rocks from Southern Rhodesia, almost exactly similar to those under discussion, has shown that a more probable source of the solutions is large intrusions of granite found, in that country, in contact with the ultrabasic rock which there becomes progressively more altered as the granite contact is approached (9, p. 89). In the Qala en Nahl area the whole of the exposed masses of ultrabasic rock are completely altered, and the serpentine is always found in contact either with the older gabbros or with the basal schists. There are, however, at no great distance from the ultrabasic rocks large bodies of granite, and these are a possible source of the solutions which caused the serpentinization; though, if this be the case, it seems necessary that further large bodies of granite underlie the whole district.

At some period later than the general serpentinization, carbonates were introduced into the serpentine, and the talc-carbonate rocks with their quartz-carbonate cores were formed along definite lines parallel to the foliation of the country. It has been shown by Keep (9, p. 104) that the addition of silica and carbon dioxide, or of carbon dioxide alone, to serpentine should result in the formation of talc and magnesite, and that this reaction is accompanied by dehydration and should be furthered by pressure which, according to van Hise, tends to cause the dehydration (1, p. 1079). The whole of the serpentine is carbonated and foliated, and both carbonation and foliation are especially pronounced in the talc-carbonate rocks which have been formed along crush zones. With the exception of the silicified serpentines of different origin, quartz is only found abundantly in the cores of the talc-carbonate masses. The complete alteration of serpentine to magnesite should result in the liberation of silica, and this alteration of the serpentine to talc-carbonate rock with the formation of quartz along the lines of maximum alteration may well have been effected by the invasion of carbon dioxide rising from some deep-seated source. This alteration took place prior to or during the period of pressure which gave rise to the foliation, for the larger carbonate aggregates tend to form the centres of augen, though in the groundmass of the rock, the smaller carbonate crystals show no signs of crushing and antigorite flakes formed during the foliation are themselves replaced by carbonate.

The talc-carbonate masses have been torn into elongated bodies by movements which took place after the hydrothermal action had ceased, since the talc-carbonate rocks are faulted against talc-free serpentine along slickensided planes. These last movements do not seem to have disturbed the quartz filigree in the core-rock, so that either this quartz is of late origin or else the core-rocks behaved as strong members with cushions of weak talc-rocks on either side.

In some places, as previously noted, the serpentine has been silicified without the formation of talc and carbonate. This silicification is apparently connected with quartz veins which traverse the whole region and are later than all the rocks with possible exception of the newer intrusions. These veins are abundant in the schists around the granites of the Ban-Balos area, but are almost absent from the schists of the Beila area, which suggests that they are connected with the former group of intrusions. It has been shown that the granites are later than the intrusion of the ultrabasic rocks, but it is likely that the foliated Beila granite is earlier than or contemporaneous with the serpentinization. It appears probable, therefore, that granites of similar age to those of Jebel Beila were the source of the carbonate solutions which altered the ultrabasic rocks to serpentine and talc-carbonate rocks, whilst the granites of the Ban-Balos group did not carry much carbon dioxide and only siliceous solutions which formed the quartz veins and effected simple silicification of the serpentine.

COMPARISON WITH OTHER AREAS.

Occurrences of serpentine, chromite-bearing serpentine, and carbonated serpentine are known in many places, but the only region in which associations of rocks comparable with those of Qala en Nahl are found is in the Belingwe-Selukwe-Gwelo mineral belt of Southern Rhodesia. With this district the similarity is very striking: indeed some of the descriptions of the magnesian rocks from that area might well have been written of Qala en Nahl, and this is especially true of the Shabani (9) and the Que-Que (10 and 11) areas. In both districts ultrabasic rocks were intruded into a series of basal schists. The former are now represented by serpentine and carbonated rocks and in both cases their intrusion was followed by an older and a younger granite. In Southern Rhodesia it is usual to find that the granite is in contact with the ultrabasic rocks, and that the degree of alteration of the latter varies with the distance from the contact: a fact which has led the officers of the Southern Rhodesian Survey to infer that the alteration of the ultrabasic rocks has been brought about by solutions emanating from the granites. As a result of this progressive alteration, the quartz-carbonate rocks usually occur at or near the granite contact and are followed by talc-carbonate rock and further away still by serpentine or partially serpentinized dunite, which sometimes forms residual kernels in the talc-carbonate rock. In the Qala en Nahl area the alteration is most intense along lines in the ultrabasic rocks now occupied by the lenses of talc-carbonate rock and, as has been noted above, bears no direct relation to granite contacts. An exact counterpart of the lenses of talc-carbonate rock with their quartz-carbonate cores is apparently unknown in Southern Rhodesia, but at Gaika Mine, Que-Que, Morgan (10) has described lens-shaped outcrops of quartz-carbonate rocks along zones of fissuring in the talc-carbonate rock, which there forms the main mass of the ultrabasic intrusion and only includes residual bodies of serpentine. The quartz-carbonate rocks there are similar to those of Qala en Nahl and, by underground mining, it has been shown that along the centres of the lenses, dykes of highly carbonated porphyrite have been intruded. These dykes, or rather the fissures into which they were intruded, have evidently acted as the channels along which the carbonating solution rose, and possibly similar dykes may exist below the quartz-carbonate cores of Qala en Nahl.

In Southern Rhodesia and other serpentine areas, surface silicification is very common. Some of the silicified serpentines of Qala en Nahl may be of this type as may also the birbirites of Abyssinia (8), but it has already been shown that one occurrence at least has probably another origin.

The chromite ore-bodies of this region are all lens-shaped masses, usually with faulted boundaries, and are very similar in their mode of occurrence to those of Selukwe and other areas of similar rocks. There are no banded ores, however, like those found in the great dyke of Southern Rhodesia (6).

The age of the basal schists of Qala en Nahl is uncertain, but from their lithological characters they seem comparable with basement schists in other parts of Africa, and since both the serpentines and the older gneissic granites are intrusive into them they are probably of very early date.

The area was mapped during an expedition undertaken by Messrs. Tanganyika Concessions, Ltd., to whom our thanks are due for permission to publish this paper. We have also to thank Mr. G. W. Grabham, the Sudan Government Geologist, for many suggestions in the field and the loan of much useful material. Dr. F. Coles Phillips kindly lent us slides for comparison and Professor A. Hutchinson allowed us to see a manuscript concerning the epidote of Beila. We extend our thanks to them and also to Professor W. G. Fearnsides for much helpful discussion. We are indebted to Mr. F. Higham, of *The Mining Magazine*, for the use of the plate for Fig. 2.

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EXPLANATION OF PLATE XVII.

FIG.

1.—Antigorite-serpentine showing the original olivine structure outlined in magnetite grains which are now surrounded by secondary carbonate. Ordinary light, × 26.

2.—Talc-carbonate rock. Uncrushed crystals of carbonate set in a groundmass composed of sheaves of talc fibres. Ordinary light, × 26.

3.—Antigorite-serpentine showing "thorn" structure. Crossed nicols, × 26.

4.—Antigorite-serpentine showing "gestrickte Struktur", × 26.

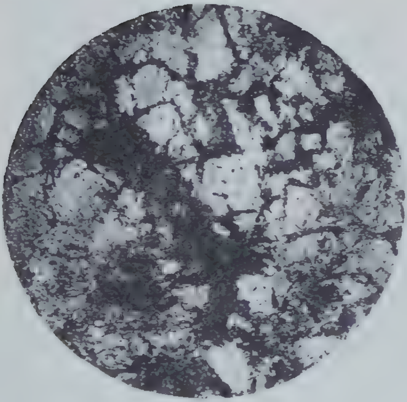

Fig. 1.

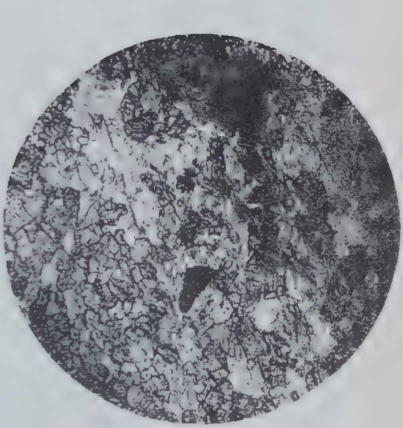

Fig. 2.

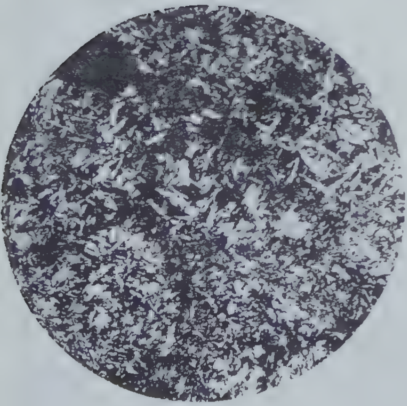

Fig. 3.

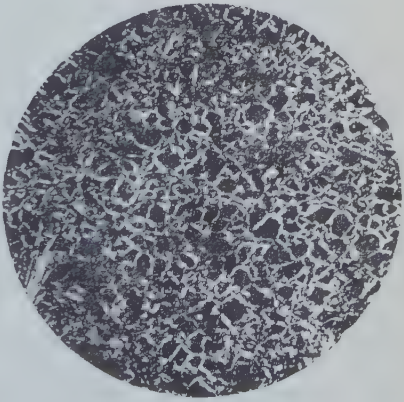

Fig. 4.

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Metamorphic Rocks of the Eastern Andes near Cuenca, Ecuador.

By George Sheppard, D.Sc., Ph.D., F.G.S., and G.H. S. Bushnell, M.A., F.G.S.

THE object of the present paper is to describe certain metamorphic rocks which occur in the eastern cordillera of the Ecuadorian Andes, immediately to the east of the interandine basin of Cuenca (Fig. 1). The latter region contains a series of late Tertiary volcanic breccias, followed by hard white shales which are overlain in their turn, and possibly in part replaced laterally by the massive, white, saccharoidal and tuffaceous sandstones of Azogues, in the composition of which rearranged volcanic ash and detritus play a large part (Fig. 2). These beds, originally described collectively as the Azogues Sandstone by Wolf (1),[1] were considered to be of Wealden age upon the evidence of a meagre lacustrine fauna discovered by the same author, and subsequently described by Dr. Geinitz, of Dresden, which were found in the more shaly sandstones of the group. A more extensive collection of fossils

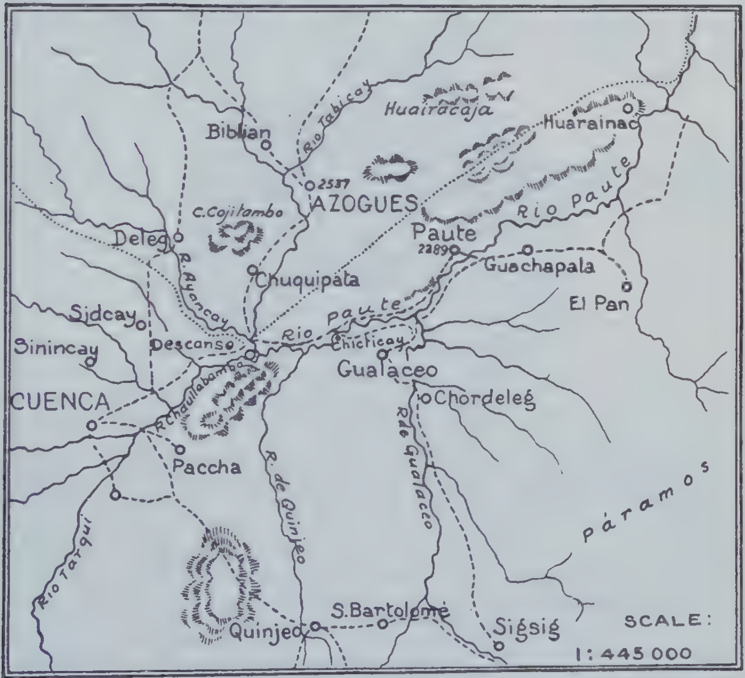

Fig. 1.

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[1] Figures in parentheses relate to References at the end of this article.

made by the present writers from the same beds and localities was submitted to Dr. W. B. Marshall, of the United States National Museum, who reports that it consists largely of new genera and species, and that the age cannot be later than the Pliocene, and it may be earlier (2). These beds are thrown generally into a series of relatively gentle folds, having a north-south trend, but occasionally they are found in a more highly disturbed condition as, for example, on the Biblian-Azogues road, where they are sometimes seen to be vertical. The strike of the folding shows that it is a product of pressure from the same direction as that which accompanied the main Andean uplift.

The section under consideration occurs along the road which leads east from the Cuenca Basin at Descanso to the village of Gualaceo (Fig. 3). A mule trial leaves this at the bridge of Chicticay, some 7 kilometres from Descanso, and passes eastward by way of the small town of Paute, through the settlement of El Pan in the heart of the eastern Andes, to the forests of the Oriente.

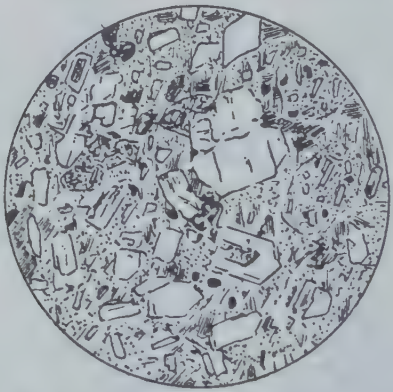

Fig. 2.—Sketch (× 25) of section of Azogues Sandstone collected at Descanso, Ecuador. The rock is tuffaceous and includes fragments of lava, in addition to felspars and quartz fragments.

It is well known that a considerable part of the Eastern Cordillera in Ecuador is composed of schists of uncertain age, and this area forms no exception, in that the schists appear about 4 kilometres east of Descanso and occupy the whole section from this point to Gualaceo and through Paute to El Pan, beyond which the trail was not followed. The width of the metamorphic zone probably exceeds 40 kilometres, of which the present observations cover the western 25 kilometres only and do not refer to the eastern slope of the cordillera. In contrast with the altered formations previously studied further north and on the eastern slope by Colony and Sinclair, no plutonic rocks were observed in the present region, and hence the special types described here do not present injection or other features ascribed to the proximity of large plutonic masses as were noted by the above authors. It is possible, however, that plutonic rocks may occur further east in the section. If schists similar to those described in this paper from the Gualaceo-Descanso zone exist further north, they must be hidden under the recent lavas which were developed to a greater extent there, viz. between Papallacta and Quito (3).

Some twenty-five specimens were collected and nineteen thin sections made from the critical part of the section between Descanso and Chicticay, and further groups of six and three rocks respectively from Gualaceo and El Pan were sliced.

A general field description will be given, followed by details of the sections.

(1) *Descanso-Chicticay.*—Descanso lies at the confluence of the rivers Chaullabamba and Ayancay, where they unite to form the Paute, flowing eastwards from the Cuenca Basin. The river Paute plunges immediately into a deep gorge, along which the road has been constructed with considerable difficulty. The river continues for some 10 kilometres to the east, after which the valley broadens out for a short distance near the strike stream Gualaceo, which joins it from the south. The Azogues Sandstone is present near Descanso, and is underlain by a thin basal conglomerate composed of small pebbles of decomposed lava. The sandstone formations here dip in a general westerly direction at about 35 degrees and are underlain by a great mass of andesite, which appears to have been inclined in the same direction as the sediments. This continues with little variation for about 4 kilometres to the east, after which the schistose series appears. The latter consists, in this part of the section, chiefly of black, imperfectly cleaved phyllites containing concretions, alternating rapidly with bands of greenish schist. Small quartz lenses and occasional beds of black shale are sometimes present. Near the top of this series there is an easily recognized band of andesite about 10 feet in thickness, which is apparently conformable with the schistose rocks, and the thin sections prove that the greater part of the greenish schists are andesites in various stages of foliation

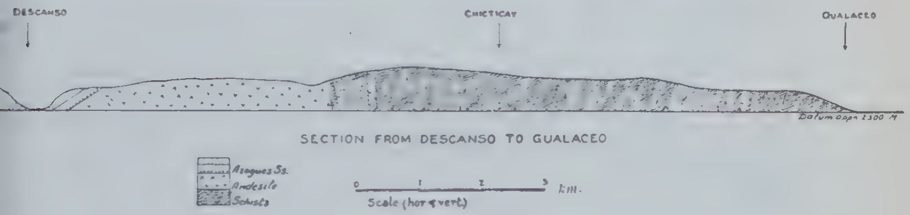

FIG. 3.

and alteration. At the bridge of Chicticay lenticles of this igneous rock can be seen with phyllites arranged in a foliated manner around them. The strike varies little from the north and south direction of the Andes, and the dips are steep, approximating in most cases to the vertical. The whole group may be classed as phyllites with chlorite-epidote schists. The evidence strongly suggests that the series consisted originally of alternations of shales with lava flows, culminating in the great development of slightly altered andesite which directly underlies the Azogues Sandstone, and that the pressure which caused the foliation in the lower part of the series was unable to impress itself on the principal mass of the andesite, though it is possible that part of the same flow was extruded during or after the tectonic movements.

The andesite is very closely allied to the recent lavas of the Andes, and in the hand specimen would be hard to distinguish from them. While the groundmass and the felspar phenocrysts have been considerably altered, some of the hornblende remains fresh. (specimen No. 2). The same applies to some of the lavas included in the upper part of the schistose group, e.g. specimen No. 4, which though much altered still contains fresh augite. Another example from within the schists, which has apparently escaped serious crushing, consists of a felted mass of small fresh crystals of felspar, interspersed with minute grains of epidote, the latter being the only signs of alteration. These facts, and the generally low grade of metamorphism in this zone, indicate that the schists and lavas composing it are of no great age.

The folding of the Azogues Sandstone and the associated rocks shows that crustal movements continued into late Tertiary times, and it is suggested that the phenomena, which caused part at any rate of the schistosity, were also responsible for the uplift which formed the lake-basin into which the Azogues Sandstone was deposited. It is indeed possible that they were contemporary with the known Oligocene-Miocene movements of the coast belt, some 125 miles to the west-north-west.

The schists of the Eastern Andes have been considered generally to be pre-Palaeozoic (4) and the greater part may well be of this age. The section under present discussion, however, seems to point to their being of more than one period, the latest falling within the Tertiary. Rocks from the more easterly part of the same neighbourhood, to be noticed below, support this contention, as they show a generally higher grade of metamorphism than the chlorite schists, and this may be possibly ascribed to their having suffered change at more than one period of their history.

(2) *Gualaceo.*—The majority of the specimens collected from here are apparently altered lavas, but their grade of metamorphism varies very little from that of the Chicticay area, and they can still be classed as chlorite schists. There is one definite example of a garnetiferous mica-schist, no doubt derived from an argillaceous

rock, which indicates that the sediments are beginning to show the effects of more intense metamorphism, as Gualaceo lies some 8 kilometres within the schistose zone.

(3) *El Pan.*—All the specimens collected here have been proved to be mica-schists, and they may be compared with some of those found at Banos, near Ambato (5). More extensive collecting in this locality, and to the east of it, is desirable.

List of Rock Sections figured and described below.

(1) *Andesite.* Descanso near the entrance to the Paute gorge.
(2) *Hornblende-andesite.* Confluence of the rivers Paute and Quinjeo.
(3) *Schist.* Locality as (2).
(4) *Altered Andesite.* Collected from within the schists in the Paute gorge east of Descanso.
(5) *Chlorite-schist.* Near the Chicticay bridge.
(6) *Phyllite* (with lenticles of andesite). Paute gorge, also (6*a*).
(7) *Schist derived from lava.* Gualaceo.
(8) As (7).
(9) *Garnetiferous mica-schist.* Gualaceo.
(10) *Mica-schist.* El Pan.

Specimen No. 1. From Descanso at the entrance of the gorge of the river Paute. This is a normal andesite for the region and is a compact, dark grey, finely crystalline rock, the weathered surfaces of which are stained by limonite. The material is hard and vitreous, breaking with difficulty in a conchoidal manner.

The microscopic details are as follow. The groundmass is almost wholly crystalline with little, if any, residual glass. Felspars of two generations of clear and relatively fresh crystals are found, the larger phenocrysts being twinned on the albite law (probably labradorite) and are occasionally present as glomeroporphyritic aggregations. These crystals are usually fractured and occasionally enclose specks of opaque magnetite. Biotite occurs but sparingly and the rock is singularly poor in hornblende or augite. The greenish brown hornblende is not well developed, and is probably largely serpentinized with an ample separation of magnetite. Epidote is an important accessory mineral and occurs in minute crystals, with a greenish yellow colour, high R.I., and perfect basal cleaveage. This mineral appears to occur universally throughout the groundmass and is also enclosed in a poikilitic manner by the felspars. Certain of the latter also are full of thin, transparent needles of a microscopic size, and can barely be resolved under a magnification of 100; some of these may be apatite.

The association of magnetite and epidote is constant and indicates a reduction or alteration of some pre-existing ferro-magnesian constituent of the rock. Not infrequently a nucleus of a brownish striated mineral, possibly biotite, occurs in the epidote-magnetite aggregations. The rock is relatively fresh and undisturbed and presents no features suggestive of excessive dynamic or other influences subsequent to its extrusion.

Specimen No. 2. Confluence of the rivers Paute and Quinjeo. A light grey rock of the order hornblende-andesite, with elongated crystals of black hornblende visible in the freshly broken hand specimen. It occurs in the main andesite mass just above the schists.

Under the microscope the type shows signs of considerable alteration. In the first instance the rock was well formed hornblende-andesite of a porphyritic habit. Under ordinary light, however, the felspars are difficult to recognize as they are so decomposed, and they appear to form part of a highly confused groundmass. Between crossed nicols the original boundary of the felspar phenocryst (plagioclase of the form labradorite-anorthite) can sometimes be seen, with occasional twinning.

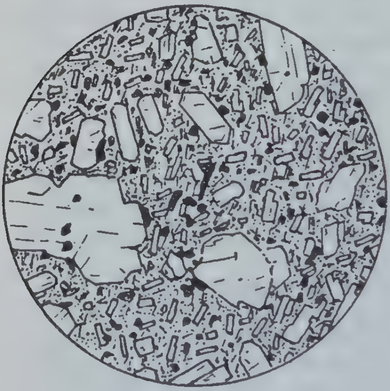

Fig. 4. × 25.

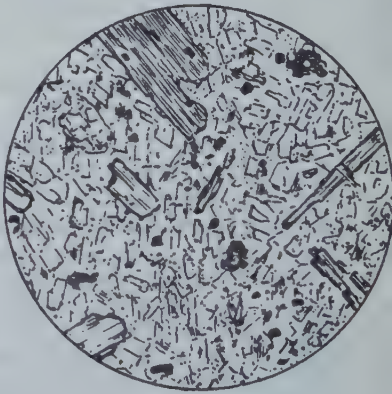

Fig. 5. × 25.

Hornblende, a greenish brown variety, is an essential mineral of the rock, and although it has mostly been converted into green chlorite, or in some cases reduced to a heterogeneous complex of iron oxide, chlorite, and calcite, a few crystals are fresh enough to indicate the characteristic cleavage. Magnetite is a constant accessory and occurs disseminated throughout the groundmass in opaque crystals, being probably an original constituent. Bluish green chlorite, possibly of the form clinochlore, forms one of the commoner alteration products in the rock. Granules of clear quartz are present also in minor proportion, and no doubt represent products of decomposition.

Calcite is a fairly common constituent of secondary origin and usually occurs in association with the small granules of quartz above referred to. Both the latter minerals are possibly a direct result of the alteration of the essential lime-felspars of the original andesite.

Specimen No. 3.—Confluence of the rivers Paute and Quinjeo. This rock is an example of a lava which has become converted into a schist, and is a light bluish grey finely foliated rock. Under the microscope the schistose nature of the rock is at once apparent, the foliation including as nuclei the felspars of the original andesite.

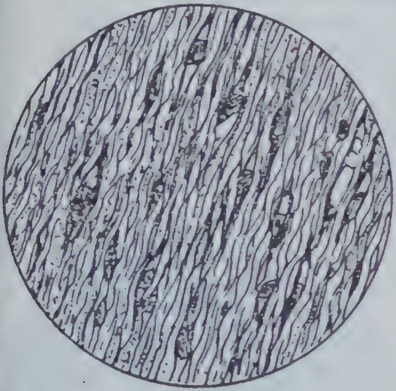

Fig. 6. × 25.

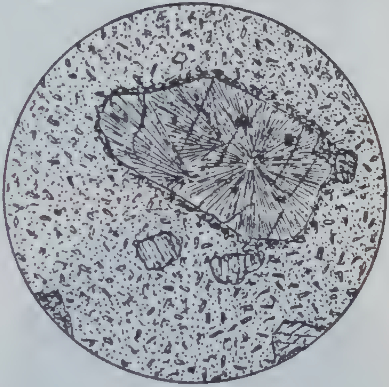

Fig. 7. × 25.

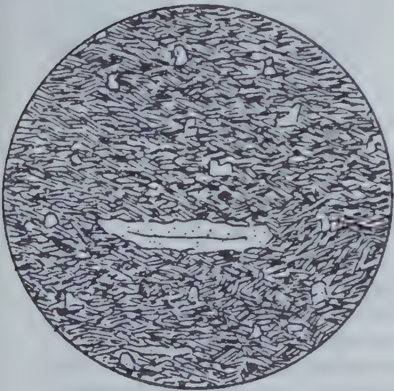

Fig. 8. × 25.

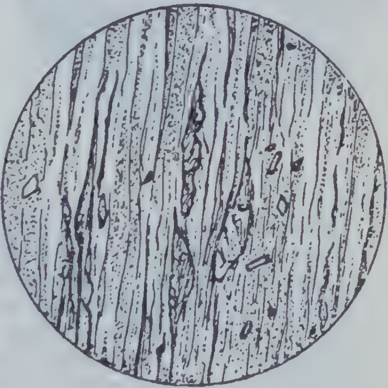

Fig. 9. × 25.

These felspars are often decomposed and turbid, but sometimes are clear, though in the form of shattered fragments. The folia of the rock consist of light greenish chlorite, in which specks of magnetite and lenticles of chlorite are present.

Specimen No. 4.—Ravine of the river Paute to the east of Descanso. The rock is an altered andesite collected from an inclusion in the schists, and consists of a slate-grey compact rock, with small, opaque felspars. The material is metamorphosed and was originally in the form of an augite-andesite. It consists of a fine-grained groundmass of minute felspar laths, probably labradorite, in a felted mass, and indicates considerable decomposition with a separation of epidote. Phenocrysts of augite are present, sometimes clear and fresh, though shattered, but often the crystals are completely decomposed. Occasional pseudomorphs after felspar (zeolite ?) are seen where the original mineral has been transformed into groups of radiating fibres, with pronounced reaction-borders. In some examples the felspar has given rise to a complex, chiefly of calcite, which is surrounded by a zone of opaque decomposition products.

Specimen No. 5.—The bridge near Chicticay, river Paute. This is a bluish grey compact rock, a chlorite-schist, though it has the appearance in the hand specimen of a fairly recent lava. Under the microscope it is evident that the rock was originally a vesicular lava which became altered into a schistose form by later metamorphism. Most of the felspars and ferro-magnesian minerals have been reduced to chlorite and calcite, the former being probably of the form clinochlore. The latter mineral often occupies the original vesicles of the lava. The following minerals have been also recognized in the schistose groundmass, granules of magnetite, altered plagioclase felspar, specks of epidote, and small fragments of quartz.

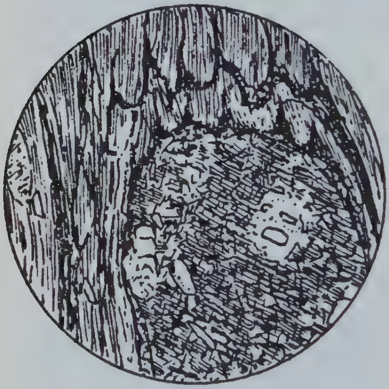

Fig. 10. × 100.

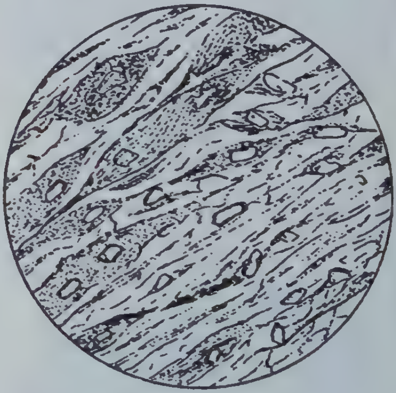

Fig. 11. × 25.

A somewhat similar example to the above rock was collected also at Gualaceo.

Specimen No. 6.—Valley of the river Paute. This is a schistose form which occasionally encloses well-marked folia of andesite. In the hand specimen the rock is light grey in colour and possesses a definite foliated structure. The rippled habit of the rock is a conspicuous feature under the microscope, and it characterizes the the whole rock. The individual lenticles, or minute "augen", consist principally of plagioclase felspars, whilst other minerals include iron oxide (limonite), graphite, magnetite, quartz, and probably fine shreds of a sericitic mica.

A diagnostic feature of the rock, and one which gives a conclusive idea in regard to its origin, is the presence of lenticles consisting of elongated inclusions of lava (Fig. 10) containing plagioclase felspars. Calcite and veinlets of limonite are also present in association with the lenticles of the schist.

Specimen No. 7.—Gualaceo. The hand specimen is a light, bluish grey rock with slight evidences of foliation, and has the general appearance of a crushed or sheared lava with a saccharoidal texture.

This is a clear example of a lava which has been subject to alteration in the form of shearing or crushing. It consists of plagioclase felspars (andesine), the latter much shattered and strained, and contains numerous inclusions in the form of minute needles. Other felspars are still relatively clear, though embedded in a turbid, kaolin-like complex which contains colourless chlorite.

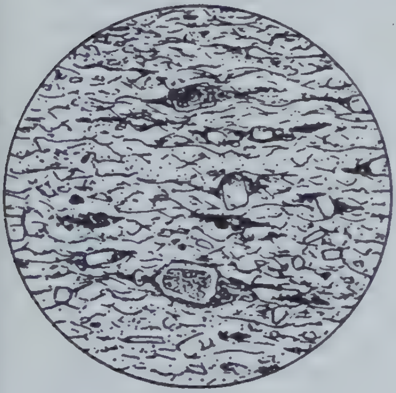

FIG. 12. × 25.

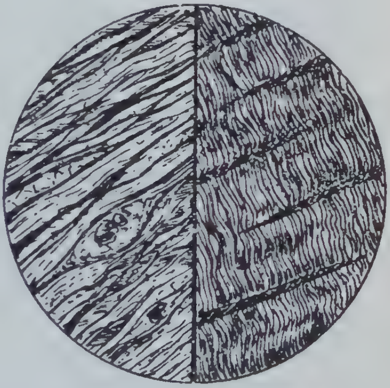

FIG. 13. × 25.

Though rare, shattered and almost completely decomposed crystals of colourless pyroxene can be identified in the section, in places the rock is almost coarse enough for it to be classified as a gneiss.

Specimen No. 8.—Gualaceo. This is an example of an andesitic lava, the structure of which has been completely transformed by the action of dynamic metamorphism. The felspars (acid labradorite), the majority turbid, usually form nuclei of small lenticles, and the whole rock has a distinctly foliated habit, the planes of foliation causing an undulatory effect throughout the groundmass.

Magnetite occurs in small granules, following the general trend of the foliation, and ferro-magnesian minerals are conspicuously absent. Interstitial calcite and flakes of sericite are present, though quartz is rare.

Specimen No. 9 (Fig. 13, left half circle).—Gualaceo. Garnetiferous mica-schist. This is a strongly foliated schistose rock with pronounced "augen" enclosing garnets, and subsidiary lenticles containing a mosaic of quartz and calcite. The mica, which forms the principal folia of the rock, is a secondary form (cf. sericite) and occasionally this is intimately associated with microgranules of quartz and magnetite. The latter mineral also is often disposed in a marginal fashion to the respective lenticles, and it occurs in specks arranged parallel to the foliation of the rock. Although it is impossible to state with certainty, owing to the altered condition of the groundmass, it is extremely probable that several of the nuclei of the lenticles were originally in the nature of lime felspars, the latter having been resolved later into aggregates of quartz and calcite. Evidences of original pyroxenes and amphiboles are meagre and rarely recognizable, yet occasional shreds of chlorite along with greenish sericite, may indicate their previous existence as rock constituents.

Grains of epidote occur as minor and secondary minerals in the groundmass, and small garnets, probably of the form pyrope, are present.

Specimen No. 10 (Fig. 13, right half-circle).—El Pan, Province of Azuay. This is an example of a finely foliated mica-schist formed by the metamorphism of a shale. The type was collected along the valley of the river Collay, a tributary of the river Paute, to the east of Gualaceo. The rock has a certain lithological resemblance to the phyllites found in the vicinity of Pelileo in the valley of the river Patate, to the north of the present region (5).

The extremely metamorphosed condition of the rock is indicated by the rippled foliation, with lenticles of quartz and the inclusion of much carbonaceous material (graphite), and by the shear zones which cross the principal lines of foliation at right angles.

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(2) Marshall, W. B., and Bowles, E. O. "New Fossil Freshwater Molluscs from Ecuador," No. 2946, *Proc. U.S. Nat. Mus.*, lxxxii, Art. 5, 1932.
(3) Colony, R. J., and Sinclair, J. H. "Metamorphic and Igneous Rocks of Eastern Ecuador," *Ann. New York Acad. Sci.*, xxxiv, 1932.
(4) Ibid., p. 4.
(5) Sheppard, George. "Igneous and Associated Rocks from the Andes of Eastern Ecuador," Geol. Mag., LXVII, No. 794, 1930.

Note on Glacial Boulders at *Verulamium* (St. Albans).

By H. G. Mantle, M.I.Mech.E., F.G.S.

DURING the month of August, 1931, the writer visited the scene of the extensive works at St. Albans, undertaken by the Verulamium Excavation Committee under the directorship of Dr. R. E. Mortimer Wheeler, on the sites of the Roman cities of Verulamium.

Forming part of the exposed massive concrete floors, walls of flint, and Roman brick and tile, are seen occasional fragments and blocks of various rocks which include vein-quartz, quartzite, sarsen, and Hertfordshire Pudding-stone. Some of these in the course of excavation had been thrown out with soil and other debris on to the sides of the excavated trenches while others remained undisturbed in place. Two particularly fine detached specimens of Hertfordshire Pudding-stone were found lying on a heap of debris. One was oval in form, measured 41 inches along its principal axis, and was 35 inches in circumference. It was vividly ochreish in colour, due to the infiltration of oxide of iron. It was evidently a well-rolled boulder, and the pebbles at its surface had been planed down by attrition so as to resemble a mosaic. The other specimen was a block, roughly triangular in shape, with rounded edges, and an irregular brownish colour. It measured 44½ inches by 38 inches and was 7½ inches in thickness. The pebbles at its surface showed very slight signs of wear. These two specimens are strikingly different in general appearance.

Several boulders and blocks still form part of original floors and wall-structures, and these were especially brought to the writer's notice by Mr. F. Gilbert Carruthers as providing evidence of their presence on the site at the time of the Roman occupation.

The more interesting of these were :—

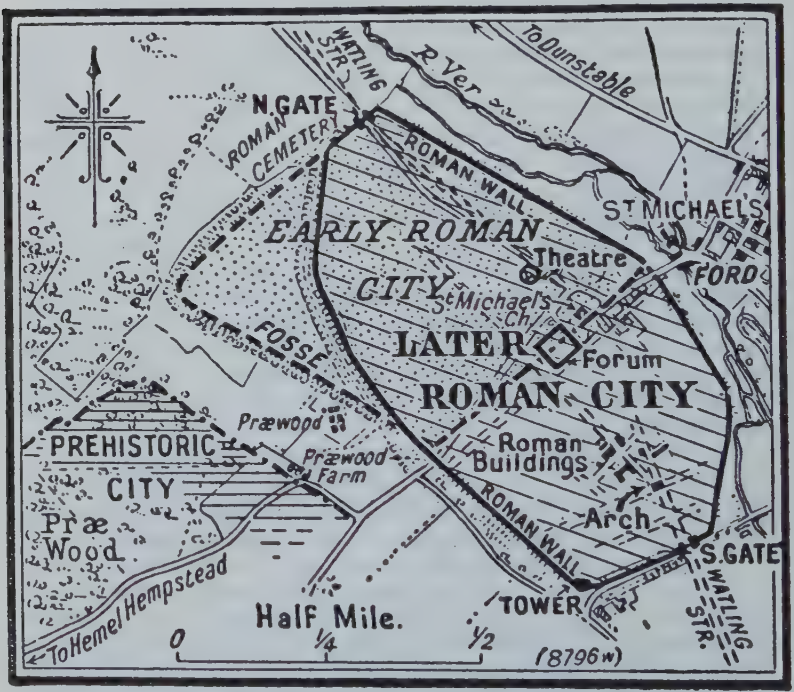
(1) An erratic of Hertfordshire Pudding-stone, oval in form, superficially much worn by rolling, and measuring 9 by 6 inches. It formed part of a fourth century floor of flints and hardened clay, and occurred at a depth of from 6 to 9 inches beneath the surface.

(2) A similar but larger boulder of the same material measuring 15 by 11 by 5 inches. It was angular in shape but the edges were rounded and its surface pebbles planed down by wear. It occurred at a depth of 30 inches from the surface, where it formed part of the wall of a third century house.

(3) Two large blocks of similar material built into the main city-wall, in the south corner of the fortifications, one by the bastion and the other by the south gate. The structure belongs to the second century.

In addition to the two detached masses of Pudding-stone described above there was also, from the same excavations, a small creamy-coloured rounded boulder of quartz. It had smooth, grooved and pitted surfaces, some of the pits being due to cavities in which a crystalline growth of quartz was visible. It possessed upper and lower planed surfaces that suggested the grinding action of moving ice. It measured 22 by 21 inches, was almost spherical, and weighed 17 lbs.

The writer, being keenly interested in the destiny of these specimens, suggested that they should be preserved in the adjoining museum as items of geological and archæological interest. As this proved impossible, the directors of the excavations gave the writer permission to make any use of the stones he might wish. He accordingly had them removed to his garden at 32 Upper Park Road, Hampstead, where they will remain in safe custody.



There is, of course, nothing unusual in the occurrence of boulders and blocks of Hertfordshire Pudding-stone in and on the superficial deposits of Hertfordshire and adjoining counties, but it is interesting to note that such masses were utilized by the Romans for building purposes some 1,800 years ago. The large oval mass of Pudding-stone from the excavations is a typical glacial boulder of far-travelled appearance, and its occurrence so near to the generally supposed source of such erratics awakens fresh interest in the location of their true source.

From Radlett near Batler's Green to Verulamium is only about

4 miles in a direct line, and Radlett has long been known as a locality where the Pudding-stone was *in situ*. Now the exposures which were open to Sedgwick, Ramsay, and Whitaker, and which were in part visible to the writer six years ago, are closed and built upon. The only evidence of their former existence is a wall about 60 yards long and up to 6 feet in height, which bounded the old quarry where the rock was exposed. This wall was built of material locally known as "motherstone", taken out of the old quarry. At the present day grave-diggers occasionally encounter the rock in Radlett churchyard, and it has then to be removed by means of explosives.

When we compare the Verulamium oval boulders with freshly fractured specimens from the exposures at Radlett and from the wall bounding the old quarry, they appear to be identical rocks; and in the opinion of the writer so are all the well-rolled boulders that he has seen taken from the gravel pits at Hanwell, from the bottom of the Travellers' Rest pit,[1] on the Huntingdon Road, Cambridge, and elsewhere.

It can also be asserted that many worn angular and subangular blocks encountered on or near the surface are of a rock identical with the true Hertfordshire Pudding-stone of Radlett. Many of these are of small dimensions.

The question naturally arises whether the great wearing down of the Verulamium boulder could be accomplished in its short journey from Radlett. If this is considered to be improbable the alternative is to derive the boulder from some yet undiscovered and more distant source of identical material.

But it appears to the writer that a detached block subjected to wear in a confined situation, such as a pothole, would meet the difficulty, all the observable rounding being accomplished in the short journey from the source.

Sometimes confused with the Hertfordshire Pudding-stone are certain conglomerates of similar nature which occur at Bradenham in Buckinghamshire. Blocks of this rock are so numerous in the valley, as well as in a large field behind the church, that Jukes-Browne was led to think that a continuous bed must have at one time existed on the hills above. These conglomerates, although sometimes referred to as Hertfordshire Pudding-stone in geological literature, are quite distinct from the Hertfordshire rock: they are coarser in texture and otherwise dissimilar. The pebbles in the Hertfordshire rock are well-rounded and of moderately small dimensions, and there is general ironstaining and complete silicification of the matrix. The Bradenham stone has irregularly shaped subrounded pebbles, a fine quartzitic sarsen-like matrix, and a general absence of ironstaining.

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[1] This erratic of Hertfordshire Pudding-stone was discovered by workmen in the Travellers' Rest gravel pit, Cambridge, at the end of August, 1925, 12 feet beneath the surface and about 12 to 15 inches from the base of the deposit which rests upon the Gault Clay. It was oval in shape, measuring 38 inches along its principal axis, and stained with peroxide of iron. No stone like it had been seen before; neither is any such rock recorded in Dr. Rastall's list or mentioned in his paper, nor in the paper of Mr. J. E. A. Whealler, which appeared in the GEOLOGICAL MAGAZINE in 1921. Small boulders of rhomb-porphyry have been found higher in this pit, 2 feet 6 inches to 3 feet from the base, which would seem to show that the drift carrying this rock was of later date than that which brought the Hertfordshire Pudding-stone.

These two types of rock, though similar in character, are lithologically distinct and also of different geological ages. The Bradenham type may be regarded as a consolidated shingle beach of early Tertiary age and the Radlett type a pebble beach of later Tertiary times (Woolwich and Reading). Both are in the nature of sarsen-conglomerates but the Bradenham type more particularly so.

The writer saw at Bradenham a large rectangular block partly composed of coarse Pudding-stone and partly of sarsen, with a fairly sharp line of demarcation between the two.[1] Such an origin is most probable for many of the blocks of Pudding-stone associated with sarsens on the Chalk areas beyond the outcrops of the Tertiaries in the South of England.[2]

Elsewhere the relatively close association of the Bradenham and Radlett types of Pudding-stone has been noted, and thus specimens of Pudding-stone must be viewed with discrimination. At Kingsbury Mill, in the ancient parish of St. Michael's, on the actual site of Verulamium, are to be seen blocks of coarse Pudding-stone several feet in diameter which resemble those of Bradenham and were certainly not derived from the Radlett outcrop, although so close to it.

The actual source of the Verulamium boulder is still an open question, but the writer considers it to be definitely of the Radlett type, as also those of the neighbouring pits at Hanwell and the boulder from the Travellers' Rest pit at Cambridge. The position of the boulder, so near to its probable source, may be in some way due to the unusual combination of circumstances operating in glacial times in the region of the Colne valley, where the nature and the great variety of erratics indicate convergence of ice streams from all directions.

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[1] The late Mr. George Barrow, F.G.S., in a paper read before the members of the Geologists' Association in 1918 (vol. xxx, page 5), cites a case where in the construction of the Rotherhithe Tunnel the engineers came on the taper end of a sarsen, which slowly thickened to about 3 feet, after which it began to contain small scattered flint pebbles; these became more numerous until the rock finally passed into a Pudding-stone.

[2] In addition to these types are conglomerates and sandstones belonging to the Bagshot series. These attain as large dimensions as the others and are of common occurrence over the same areas. For example, at the Grove, Stanmore, Middlesex, there is an unusually large collection of these blocks, as also at Stanmer Park and Falmer in Sussex.

REVIEW.

Earth Lore: Geology without Jargon. By Professor S. J. Shand. pp. viii + 134, with iv plates and 33 text-figures. London: Murby, 1933. Price 5*s*.

PROFESSOR SHAND has added another volume to the large number of small more or less popular books on geology, published during the last few years. It is a little difficult to see how all of these find a sale, but in this case the author's known reputation as an original thinker in his subject will give it a start. It may be doubted, however, whether the sub-title, "Geology without Jargon," is in reality so much of a recommendation as the author believes. The reviewer is of opinion that the reaction against technicalities, which is the real meaning of "jargon" in this context, has been a little overdone. A technical term is a form of shorthand, and if such are entirely excluded, the result is bound to be circumlocution and prolixity. It may well be maintained that the beginner in a science should learn its language at the earliest possible stage. By this it is not meant that the learner in geology should commence with long lists of fossil names, which are indeed an intolerable jargon, but surely such portmanteau words as magma, sima, and so on should be introduced as early as possible, if the treatment of the subject is to be of any educational value at all. Even a definition of isostasy saves a deal of talk.

As a second criticism it may be suggested that Professor Shand expends a good deal of space in belabouring ideas that nobody now holds seriously. Surely the time has passed by when the first chapters of the Book of Genesis and the antecedent Mesopotamian legends were regarded as text-books of cosmogony and evolution. They belonged to their age, which is not ours, but they were adapted to the culture of their age and served their purpose in their time, as well as the most modern text-books now do. It is much to be regretted that in this section of the book there is to be discerned more than a trace of the curiously narrow Victorian outlook of the publications of the *Rationalist Press*.

However, when Professor Shand gets away from this sort of thing, he has something to say that is worth attention. He is a geologist with a wide outlook, and in several chapters he gives an excellent summary of modern ideas on the constitution of the earth's interior, on vulcanicity, on mountain-building, rift-valleys, and so on, the last referring to the conception of the "ramp" origin of these structures, which has been so ably expounded by Bailey Willis. Perhaps the most interesting section of all is that on continental drift, in which Professor Shand makes it clear that he would fain believe, if he could. Perhaps Gutenberg's flow theory, very recently expounded in these pages by Mr. Lake, may help him.

CORRESPONDENCE.

A FOSSIL FISH FROM BARBADOS.

SIR,—Last year Dr. Matley published in your MAGAZINE (pp. 366–373) an article on the stratigraphy of Barbados, in which he discussed the age of the conglomerate of the Scotland Beds. In claiming an Upper Eocene Age for it, he mentioned among the fossils collected from the conglomerate by Mr. Romanes, " A Siluroid fish, *Socnopaea* cf. *grandis* Stromer, . . . represented by two fragments, a part of a cranial bone showing external sculpture markings, and a well preserved, although incomplete, pectoral spine (90 mm. long) with good articular end." Unfortunately, at the time Dr. Matley was writing his paper, the specimens were not available and the identification he quotes is from the late R. B. Newton's MS. Lately the specimens have come to hand and, as one might have suspected, I find that they do not belong to *Socnopaea* or any other known fossil Egyptian cat-fish. The cranial bone is a fragment 2·5 cm. by 1 cm. and bears a reticular ornament quite dissimilar from that of *Socnopaea*, and is quite unidentifiable. The pectoral spine is from the left side and differs somewhat in its method of articulation from that of any described fossil Siluroid and most probably represents a new species. It was apparently not found at the same time as the skull fragment, and there is no evidence to show that they belong to the same form.

As cat-fishes do not seem to have a wide range, either stratigraphically or geographically, Dr. Matley was right in emphasizing the importance of the apparent occurrence of a Fayum species in Barbados, and for this reason I think it worth while correcting the identification of the specimens.

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